M-4415

Subject Category: INSTRUMENTATION

UNITED STATES ATOMIC ENERGY COMMISSION

MANUAL OF INSTRUMENTS AND CONTROLS FOR THE BROOKHAVEN NUCLEAR REACTOR. BOOK 3, VOLUME I

May 1949

Servomechanisms Laboratory
Massachusetts Institute of Technology
Cambridge, Massachusetts

Jackson and Moreland Engineers
New York, New York

Technical Information Extension, Oak Ridge, Tennessee

Date Declassified: January 13, 1956.

Printed in USA, Charge $1.00. Available from the Office of Technical Services, Department of Commerce, Washington 25, D. C.

AEC, Oak Ridge, Tenn.

M-4415

MANUAL OF INSTRUMENTS AND CONTROLS FOR THE BROOKHAVEN NUCLEAR REACTOR

BOOK 3, VOLUME 1

Prepared by the staffs of

The Servomechanisms Laboratory

Massachusetts Institute of Technology

and

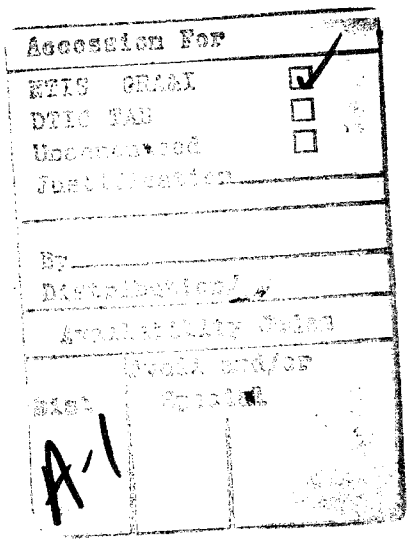
Jackson and Moreland

Engineers

Under contract to

The H. K. Ferguson Company

May 1949



This Book is

Book No. 3, Volume I

of a series written for Brookhaven National Laboratory. All books except Book No. 3 have been prepared by The H. K. Ferguson Company.

The complete series is comprised of the books listed below:

Book No. 1 ----- Design Manual

Volume 1 — General Codes and Data

Volume 2 — Utilities, General Site Service

Volume 3 — Pile

Volume 4 — Pile Auxiliaries

Book No. 2 ----- Pile Operating Manual

Book No. 3 ----- Manual of Instruments and Controls

Volumes I and II

Book No. 4 ----- Process Instrument Manual

Book No. 5 ----- Pile Maintenance Manual

Book No. 6 ----- Laboratories Manual
(Design, Operation, Maintenance)

Book No. 7 ----- Boiler House

CONTENTS

VOLUME I

CONTENTS

VOLUME I

CHAPTER I

INTRODUCTION

1. General

The instruments and controls for the Brookhaven Nuclear Reactor have evolved from a development program whose objective was, among others, to create a research facility. Throughout this program it has been clear that the ultimate arrangement of instruments and controls can not be fixed in advance of actual operation. The ultimate arrangement will depend in large measure on the research activity to take place in the future. It has been necessary, therefore, to provide a wide range of instrument capabilities and a large number of control functions.

Underlying this primary objective of creating a versatile research facility is the associated requirement that the reactor be safe. The requirements for safety are in some ways as varied and complex as those of research. In some instances they are dominant.

Exemplifying the flexibility and versatility of the reactor instrumentation are electronic instruments of advanced design for measuring power at extremely low levels, indicating and recording the rate of rise of power level over a wide range of power, and regulating power at preset levels. Exemplifying the variety of safety devices are instruments for monitoring power level detected by ionization chambers, by neutron thermopiles, and by graphite and metal-cartridge thermocouples. Devices which monitor the operability of equipment also contribute to the safety of the reactor.

Figure 1.1, "Location of Instrument and Control Equipment," shows the location of the important elements in the control system for the reactor. The view shows a control room in which are located control panels and the operator's console. The more important instruments, on the front panel, are easily read by the operator from his position at the console. Much of the instrument equipment associated with the control of the reactor is in the equipment room, located immediately below the control room. The control rods and the mechanisms for driving them are arranged in two banks on the southeast and southwest corners of the reactor. Sensing elements associated with the measurement of temperature and nuclear radiation are located in holes passing through the reactor shield.

The controls and instruments associated with the control and measurement of the power level of the reactor have been divided into the following five groups:

Control-Rod Drives

Rod-Position Instruments

Reactor-Activity Instruments

Emergency-Shutdown and Alarm Equipment

Radiation-Monitoring Instruments.

In the remainder of this chapter, each of these groups will be discussed briefly. A detailed treatment of each is given in five subsequent chapters.

2. Control-Rod Drives

Sixteen control rods are provided for the control of the Brookhaven Reactor, as shown in Figure 1.2. Fourteen of these rods (Nos. 1-8, 10-14, and 16) are designated "emergency" rods and two (Nos. 9 and 15) are designated "regulating" rods.

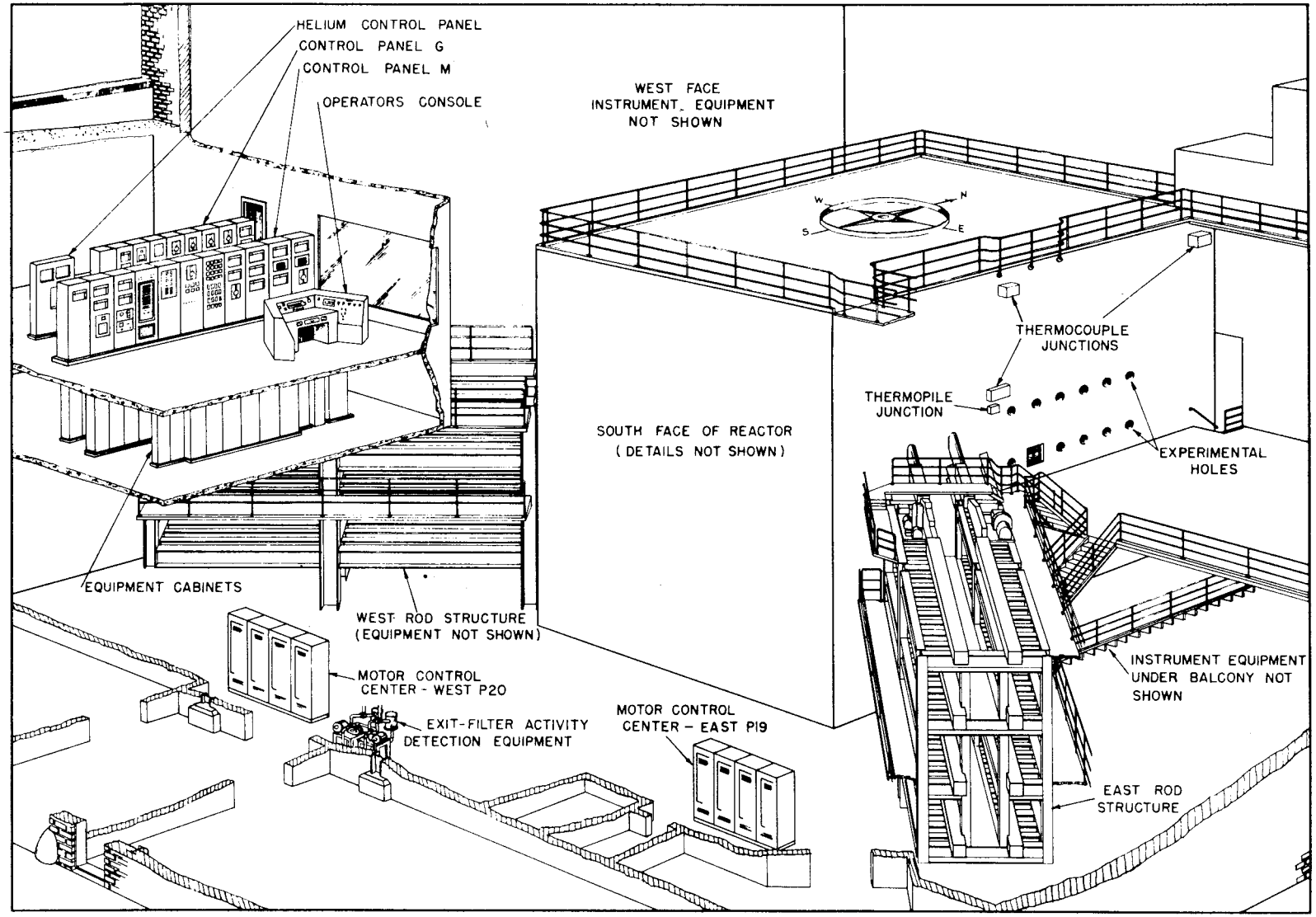
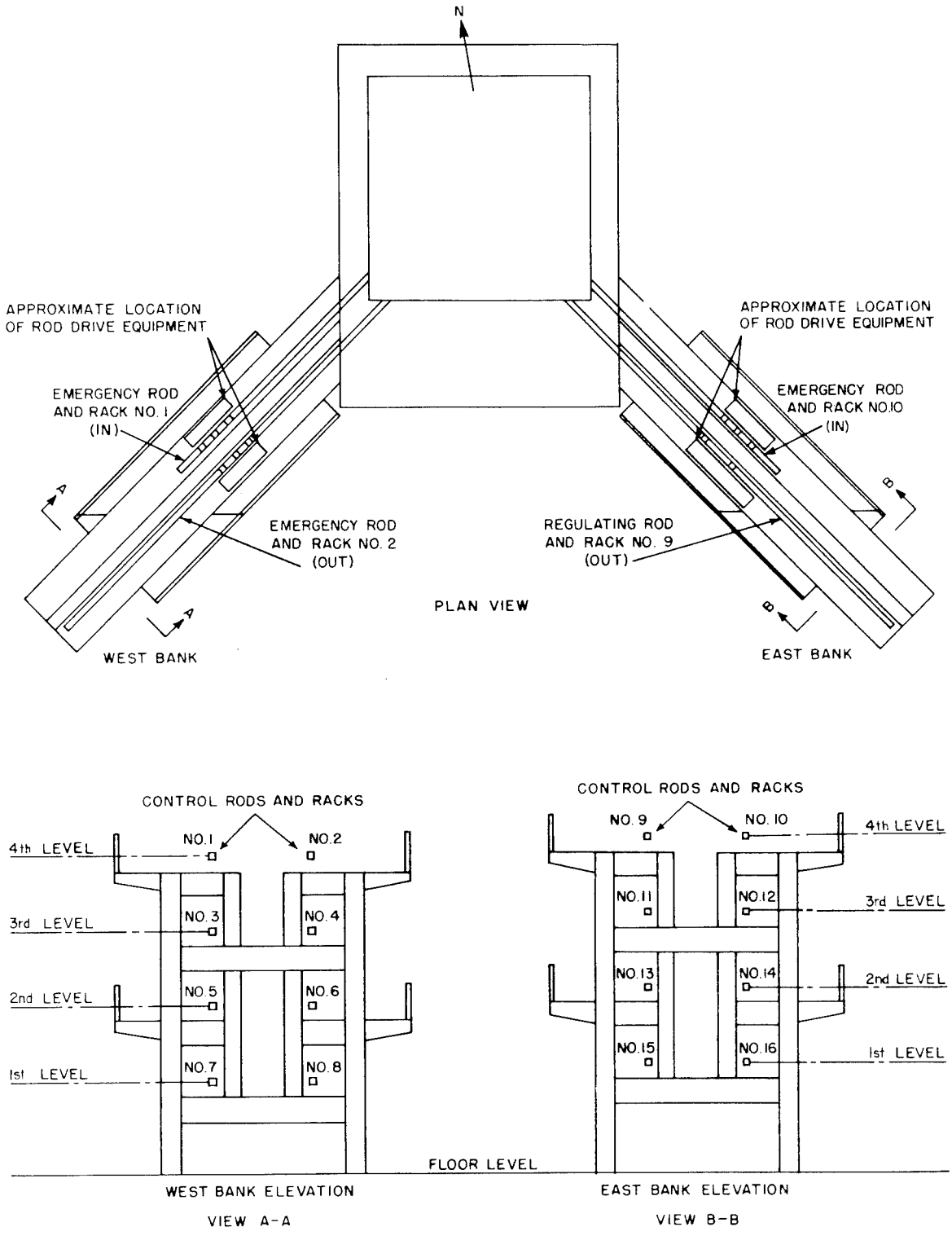


FIGURE I.1 LOCATION OF INSTRUMENT AND CONTROL EQUIPMENT



NOTE: CONTROL RODS NOS. 9 AND 15 ARE REGULATING RODS. ALL OTHERS ARE EMERGENCY RODS

FIGURE 1.2 CONTROL ROD ARRANGEMENT

The emergency rods have the two principal functions of (1) shutting down the reactor quickly in the event of hazardous conditions and (2) increasing the reactivity at the will of the operator for the purpose of starting the reactor. Each emergency rod has an independent hydraulic drive unit and can be positioned independently of all others. All of the emergency-rod drive units are so connected that, in the event of an emergency, all other control signals are overridden and all rods move to full insertion at maximum speed.

The two regulating rods are driven by independent drive units. Two induction motors, a mechanical differential and gearing are arranged so that a rod can be moved in or out at two speeds. The maximum and minimum speeds of the regulating rods are considerably less than those of the emergency rods. These rods, therefore, can be positioned more accurately. Their primary purpose is to maintain the power level once it has been established by removal of the appropriate number of emergency rods. Rod No. 9 is operated manually through push buttons on the operator's console in the control room. Rod No. 15 can be operated manually by a second set of push buttons on the console, but can also be operated from an automatic controller when it is desired that the reactor power be kept constant without being attended by the operator. Rod No. 15 operating as part of the automatic system will also assist the operator in reducing the rate of rise of power at the end of the start-up operation. Both regulating rods are connected to the emergency-shutdown system so that in an emergency they will automatically travel to full insertion, unless the emergency be loss of 440-volt power needed for their operation.

3. Rod-Position Instruments

The purposes of the rod-position instruments are to indicate and record the positions of the control rods, to assist in reactor operation, and to provide research data. Four different types of equipment are provided for these purposes. The first type, a precise indicating instrument, provides rod-position data for the regulating rods, to a precision of approximately $\pm 1/4$ millimeter. Two of these instruments are furnished, one for each regulating rod. The second type, of which there are fourteen instruments, provides rod-position data for the emergency rods to a precision of approximately ± 1 millimeter. These two types of instruments are furnished primarily as precise tools for research. The third type, of which there are two instruments, provides an approximate indication of the positions of all rods. Each of the two banks of eight control rods has its own instrument of this type, which is furnished primarily as an operational aid. The fourth type, of which there are four instruments, provides graphical records of the positions of the rods. Two of these instruments are single-line strip-chart recorders, which provide continuous records of the positions of the regulating rods. The other two instruments are eight-point strip-chart recorders, which provide intermittent records of the positions of all sixteen rods. These instruments are furnished primarily to provide operational records. All rod-position indicating and recording instruments are located in the control room.

4. Reactor-Activity Instruments

The instruments for indicating and recording reactor power and internal temperatures and for protecting against excessive power and temperatures are grouped in several systems as follows:

Galvanometer system for indicating power from full power down to about 200 watts.

Neutron-counting-rate system for indicating the reactor activity from shutdown conditions up to about 200 watts.

Neutron-counting system for use as a basic measuring device for neutron flux over a wide range.

Trip circuit for shutting down the reactor when the reactor power becomes excessive and for recording the reactor power.

Logarithmic system for indicating the reactor power over a 7-decade range, indicating the rate of rise of reactor power and protecting against excessive values of power or excessive rate of rise of power.

Thermopile system for indicating and recording reactor power at high levels and protecting against excessive power.

Thermocouple system for indicating and recording metal-cartridge temperatures and protecting against excessive cartridge temperatures.

Thermocouple system for indicating and recording graphite temperatures.

5. Emergency-Shutdown and Alarm Equipment

The safe operation of the reactor requires an elaborate interconnection of components whose purposes are (1) to shut down the reactor automatically when an important malfunction occurs and (2) to signal the operator automatically in the control room that some piece of equipment is malfunctioning or that operating levels have been exceeded. Ninety-six channels are provided for alarm purposes, fifty-six of which also cause automatic shutdown of the reactor.

6. Radiation-Monitoring System

To monitor undesirable radiation external to the reactor itself, three radiation-monitoring systems are provided. One records radioactive content of the stack gases. The second records radioactive accumulation on the filters in the coolant exit ducts. The third records the gamma-ray activity at eight selected positions in the reactor building.

The stack-air-activity system has its primary element located in the fan room. Activity indications appear on a local recorder and on a remote recorder in the control room. The exit-filter-activity system has a similar functional arrangement except that the primary elements are in the reactor building. Both systems are interconnected with the alarm annunciator to warn the operator of excessive activity.

The building-radiation monitors detect and indicate locally gamma-ray activity and record remotely in the control room on an eight-point strip-chart recorder. An interconnection with the alarm annunciator is also provided.

7. Scope of Subsequent Chapters

The next five chapters of this book discuss in detail the five systems enumerated above. Two additional chapters are included to describe the control room and the equipment room.

Each chapter commences with a statement of the function of each system and then describes in detail the equipment furnished as part of the system. A parts list and a list of references are also included.

CHAPTER II

CONTROL-ROD DRIVES

1. Introduction

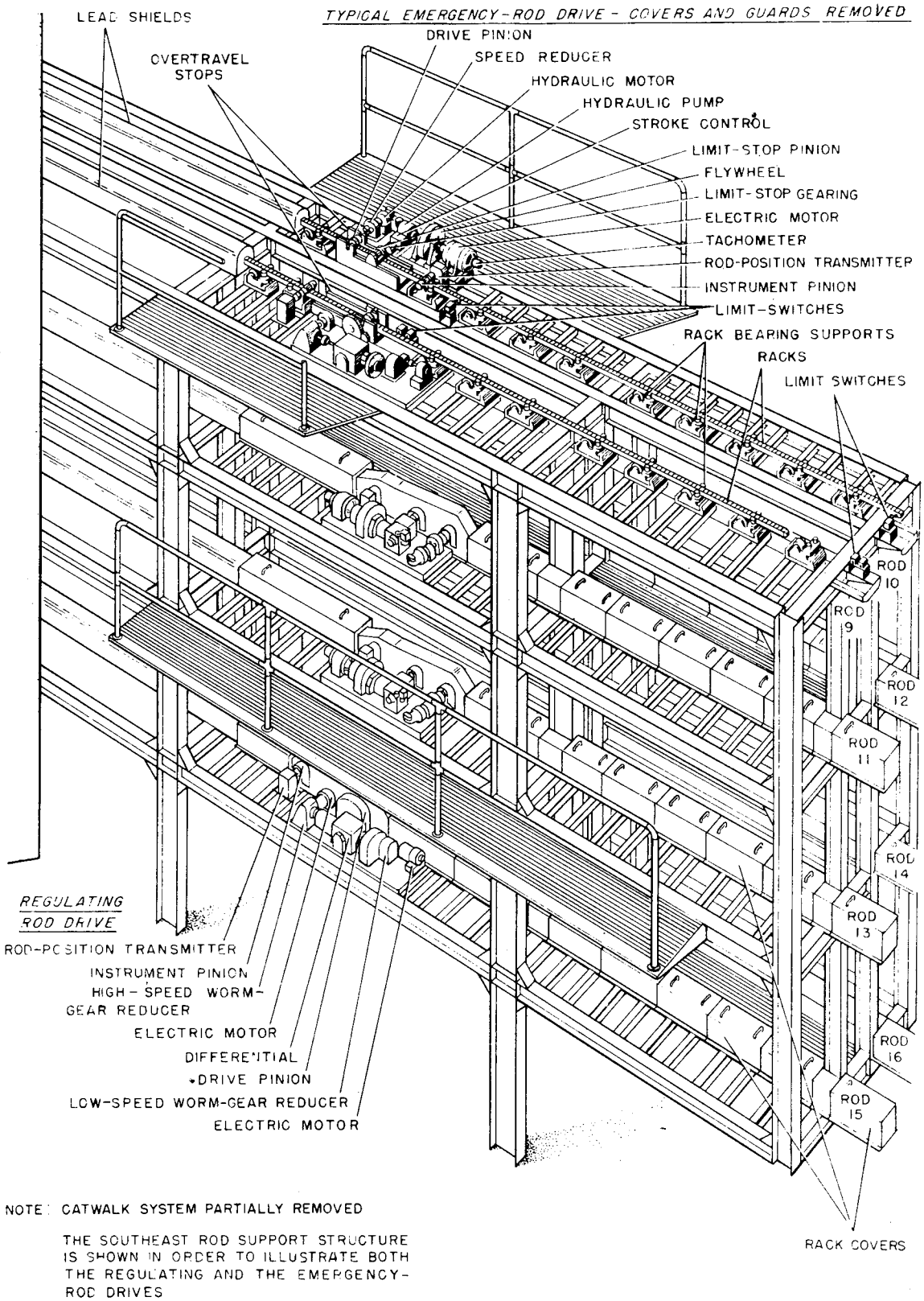
The Brookhaven Nuclear Reactor is controlled by sixteen rods arranged and numbered as shown in Figure 1.2, Chapter I. The physical arrangement of equipment located on the southeast rod structure is shown in Figure 2.1. The arrangement of equipment on the southwest rod structure is similar except that all eight rods are emergency rods. All rods except 9 and 15 are designated emergency rods. The emergency rods are used for coarse control of reactor power and for shutting down the reactor quickly in response to the emergency-shutdown system. Rods No. 9 and 15 are designated regulating rods and are equipped with drives to permit accurate manual control of reactor power. In addition, Rod No. 15 can be used for automatic control of reactor power. Hence, we have three systems of rod control which are called:

Emergency-Rod System

Regulating-Rod System--Rod No. 9

Regulating-Rod System--Rod No. 15

The emergency-rod system provides the operator with a selector switch and a set of push buttons with which he can move any of the emergency rods in either direction at either high or low speed, except during shutdown. When a shutdown signal is received, the operator's signals are overridden and all emergency rods are inserted at high speed. Each emergency-rod drive also includes a flywheel storing sufficient energy to insert the rod in case of electric-power failure. In response to an emergency-shutdown signal, the emergency-rod drives can move the rods



NOTE: CATWALK SYSTEM PARTIALLY REMOVED

THE SOUTHEAST ROD SUPPORT STRUCTURE IS SHOWN IN ORDER TO ILLUSTRATE BOTH THE REGULATING AND THE EMERGENCY-ROD DRIVES

FIGURE 2.1 EQUIPMENT ARRANGEMENT ON ROD STRUCTURE

from minimum to maximum insertion in less than five seconds. In response to signals from the push buttons, the drives can move the rods at speeds up to one foot per second. The emergency rods can also be moved by means of hand cranks without using the power drives.

Regulating Rod No. 9 has an independent control system. Through push buttons mounted on the console, the operator can move the rod in or out at either high or low speed. The rod is inserted at high speed in response to all emergencies except power failure. Since the regulating-rod drive has no energy-storage device, this rod can not be moved without electric power.

For Regulating Rod No. 15, a selector switch on the console enables the operator to choose either manual or automatic control. In manual control the rod is operated in the same manner as Rod No. 9, through push buttons located on the console. Automatic control of this rod is provided to assist the operator in bringing the reactor up to power without excessive overshoot. It can be used also to hold the reactor automatically at a preset power level. Like Rod No. 9, Rod No. 15 is inserted at high speed in response to all emergencies except electric power failure.

All rods are provided with limit-stop devices to prevent motion beyond the normal range of operation. Buffer stops are also provided to prevent equipment damage in the event of limit-stop failure.

2. Emergency-Rod System--General Description

The emergency-rod system is shown schematically in Figure 2.2. A selector switch and push buttons on the console permit the operator to

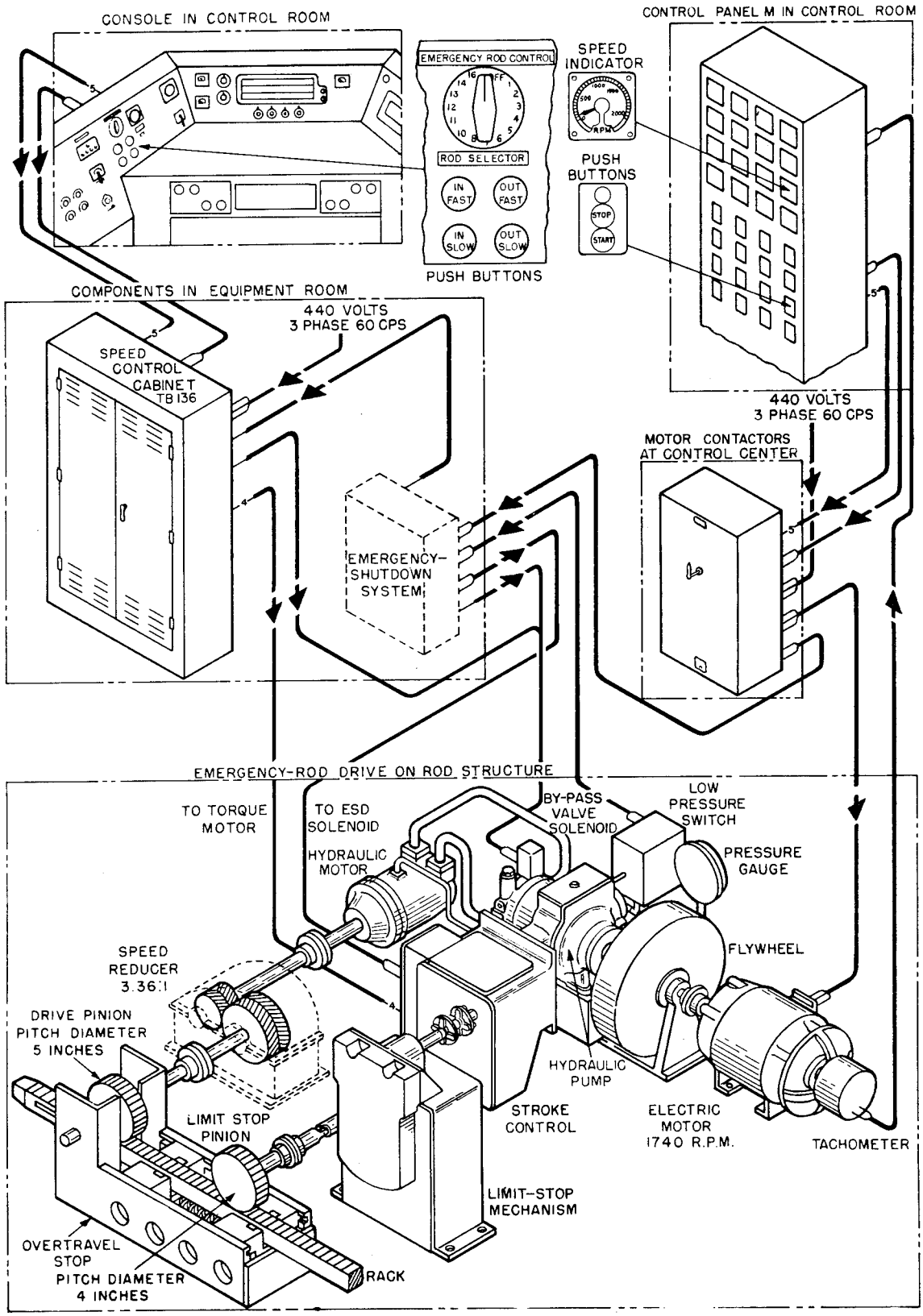


FIGURE 2.2 EMERGENCY-ROD SYSTEM

move any emergency rod at his discretion when the reactor is not in shutdown. An emergency-shutdown signal overrides operator's signals and actuates all fourteen emergency-rod drives simultaneously.

Each emergency rod is attached to and driven by a rack. The rod itself is at all times completely within the lead shielding or the reactor. The length of rack within the shielding is supported by the slideways. That extending beyond the lead shielding is supported and guided laterally by a series of rack-bearing supports fastened to the rod structure along the path of rack motion.

To prevent overtravel of the rod and rack, a buffer stop which acts directly on the rack is mounted on the end of the rod structure near the reactor. Mounted on the buffer stop and meshed with the rack is the drive pinion. The drive pinion is driven through a gear reducer by a constant-displacement hydraulic motor. Oil is supplied to the hydraulic motor by a variable-displacement pump. A stroke control attached to one side of the pump housing controls the quantity and direction of oil supplied by the hydraulic pump. The stroke control contains a torque-motor to respond to signals from the operator and a solenoid to respond to signals from the emergency-shutdown system. A solenoid actuated by-pass valve also mounted on the pump prevents creep of the hydraulic motor and, consequently, of the rod when no motion is desired. The torque of the hydraulic motor is limited by a double-acting relief valve which by-passes high-pressure oil across the high-pressure lines of the pump when the pressure becomes excessive. The hydraulic pump is driven by an electric motor equipped with a tachometer generator for motor-speed indication.

A flywheel mounted on the drive shaft between the drive motor and the pump provides energy to insert the rod if electric power fails.

A selector switch and a group of four push buttons mounted on the console enable the operator to select the desired rod, to move it either in or out at high or low speed. Signals from the push buttons actuate relays in the speed-control cabinet, TB136, in the equipment room which (1) remove voltage from the by-pass solenoid, thus closing the by-pass across the pump, (2) apply appropriate voltage to the torque motor in the stroke control of the selected rod, and (3) remove voltage from the other push buttons so that depressing one of them produces no effect. Also mounted in cabinet TB136 are the phase-shifting transformers, constant-voltage transformers, and variable-voltage auto-transformers which supply voltage to the torque motor.

An emergency-shutdown signal to the emergency-rod drive is the removal of power from the emergency-shutdown solenoid in the stroke control. De-energizing this solenoid permits a spring to move the stroke control so that the pump is on full stroke in the direction to insert the rod.

Push buttons mounted on Control Panel M in the control room start and stop the electric motors which drive the hydraulic pumps. One pair of push buttons is provided for each motor. The push buttons actuate motor contactors in the control centers which are located near the rod structures. Speed indicators mounted directly above the push buttons receive signals from tachometer generators coupled to each motor.

Other components in each pump assembly are a limit-stop mechanism, a pressure gauge, and a pressure switch. The limit-stop mechanism is driven

by the rack through the limit-stop pinion. Its output drives the stroke control to neutral when either limit of normal travel of the rod is reached. The pressure gauge indicates the pressure supplied by a small auxiliary gear pump inside the main pump housing. This pump supplies oil to replenish the main pump as well as oil to operate the stroke control. The pressure switch sends a shutdown signal to the emergency-shutdown system when the pressure falls below a predetermined value.

The specifications of the emergency-rod drives are as follows:

Maximum thrust on rod, approximately 600 lb (at 1500 psi oil pressure)

Maximum speed of rod during ESD, approximately 5.5 ft/sec

Maximum speed of rod being withdrawn from reactor, approximately 1.2 ft/sec

Maximum speed of rod being inserted under control of operator, approximately 2 ft/sec (adjustable)

Minimum dependable speed, in or out, approximately 0.2 ft/sec

3. Emergency-Rod System--Operation

3a. Electric Drive-Motor Control

To start the emergency-rod drives, the operator must first start each of the electric drive motors. Because of the long starting time of these motors, a dual contactor type of motor control is used. One contactor is equipped with high-current thermal overload elements and is used for starting the motor. A second contactor equipped with thermal overload elements set for the normal overload current of the drive motor is used when the motor is running at full speed. When the starting contactor is closed, an indicating lamp above the start and

stop push buttons is illuminated. This lamp is not illuminated when the motor is energized through the running contactor, or when the motor is without power. An auxiliary contact on the running contactor controls power to an auxiliary relay, the contacts of which are connected to the emergency-shutdown system. Hence, loss of voltage at any emergency-rod drive motor shuts down the reactor.

A schematic diagram of the control circuit of a single motor is shown in Figure 2.3. The push buttons and indicating lamp are located on section five of Control Panel M. The contactors for Rods No. 10 to 14 and 16 are located in control center P19 and the contactors for Rods No. 1 to 8 are in control center P20. (See Figure 1.1, Chapter I, for physical locations of control centers.) Power for the control circuit is supplied at 110 volts from a 440-110 volt transformer. Depressing the START button applies voltage through the normally-closed, stop-button contacts to the coil of the STARTING CONTACTOR and through a normally closed contact of RELAY RX to the INDICATING LAMP. When the STARTING CONTACTOR closes, voltage is applied to the motor through the main starting contacts. One of the auxiliary contacts closes a holding circuit through the normally-closed contact of RELAY RX. The second auxiliary contact puts voltage on one terminal of the normally-closed contacts of the START push button.

Releasing the START push button now applies voltage to the coil of the RUNNING CONTACTOR, closing its main contacts. An auxiliary contact on the RUNNING CONTACTOR parallels the holding auxiliary contact on the STARTING CONTACTOR in the coil circuit of the RUNNING CONTACTOR.

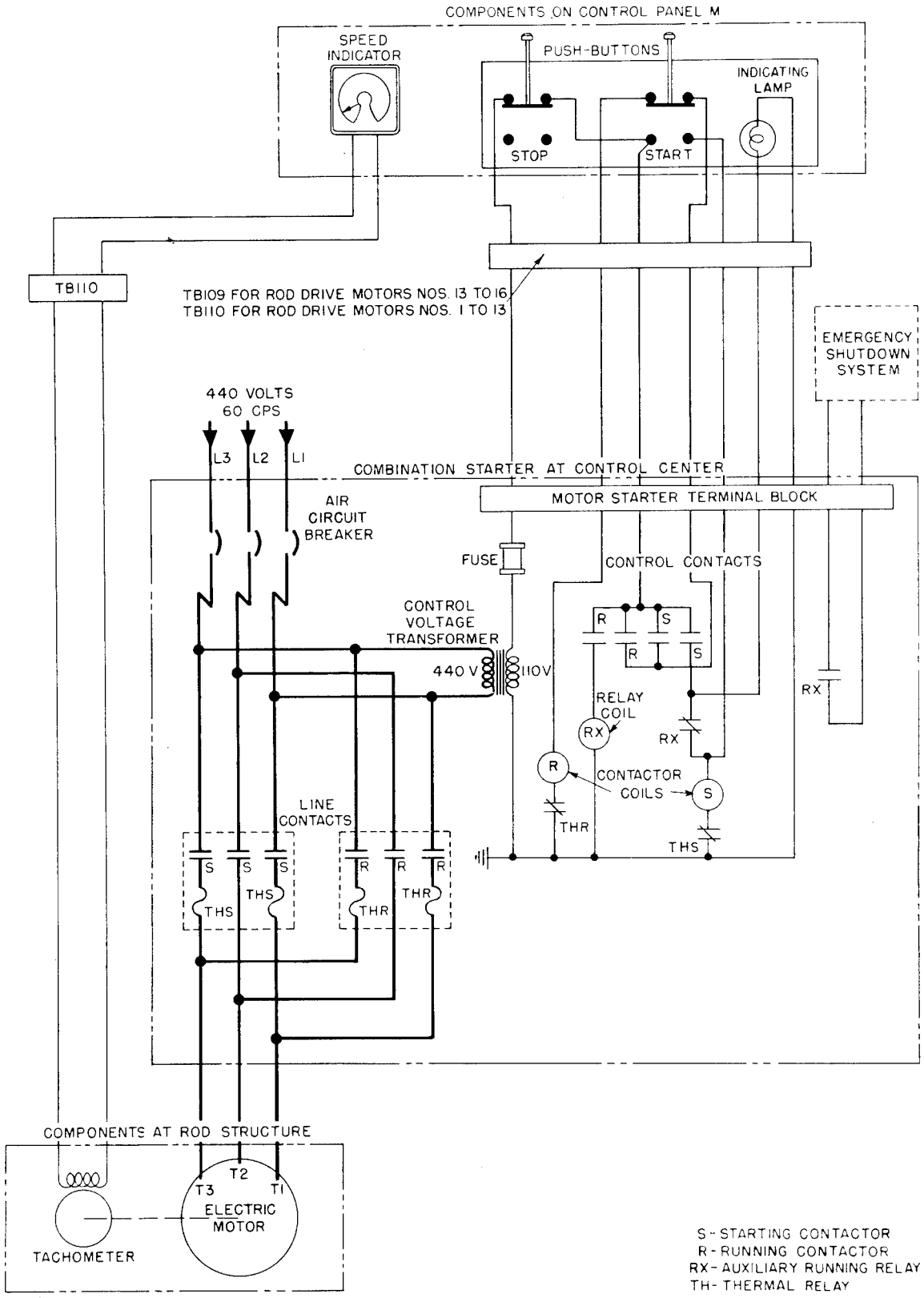


FIGURE 2.3 CONTROL CIRCUIT FOR EMERGENCY-ROD DRIVE MOTOR

A second auxiliary contact on the RUNNING CONTACTOR energizes RELAY RX. When RELAY RX operates, its normally-closed contacts open, dropping out the STARTING CONTACTOR. Its normally-open contacts close, energizing the emergency-shutdown circuit.

To start a motor, the START push button is depressed and held until the corresponding motor speed indicator reads 1600 rpm. The push button is then released as the motor speed continues to rise to its normal value of 1760 rpm. The red INDICATING LAMP which was illuminated while the START button was depressed goes out when the push button is released.

3b. Emergency-Rod Speed Control

When the reactor is under control of the operator, any one of the emergency rods can be moved by rotating the selector switch, C28,[1] on the console to the desired rod number and depressing the proper push button for in-fast, in-slow, out-fast, or out-slow motion of the rod. When one of these push buttons is depressed, relays in equipment cabinet TB136 in the equipment room (1) open the circuit through the other three push buttons to render them inoperative, (2) apply voltage to both phases of the two-phase torque motor of the selected emergency-rod drive, and (3) de-energize the by-pass solenoid of the selected emergency-rod drive. A schematic diagram of the speed-control circuit is shown in Figure 2.4. Power for the torque motors, as well as the relays, is supplied at 440 volts, three-phase, transformed to 120 volts, two-phase, and regulated at 110 volts by two single-phase voltage-stabilizing transformers. Four

---

[1] Instrument numbers appearing in the text refer to an instrument list issued separately.

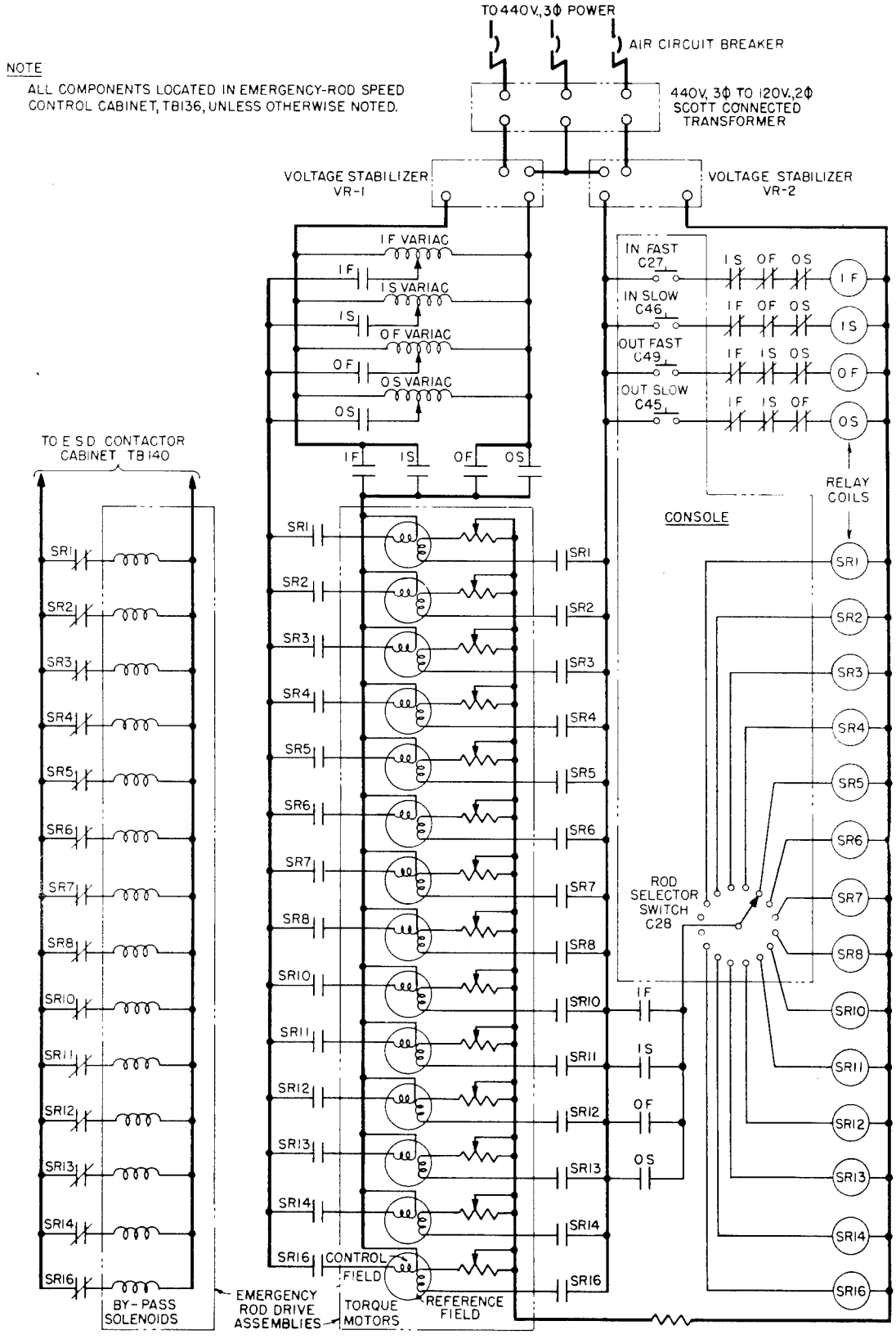


FIGURE 2.4 EMERGENCY-ROD SPEED CONTROLS

adjustable auto-transformers (Variacs) supply voltage to the torque-motor control field at the level required to obtain the desired rod speeds. Power to the by-pass solenoids is supplied through the emergency-shutdown contactor so that the by-pass solenoids of all drives will be de-energized when an emergency shutdown occurs. The equipment in equipment cabinet TB136 is further described in Chapter VIII.

If, for example, Rod No. 5 is to be moved out slowly, operation of the circuit is as follows (see Figure 2.4). The selector switch is set at 5, and the OUT-SLOW push button is depressed. Depressing the push button energizes the coil of RELAY OS, opening the normally-closed contacts of RELAY OS between the other three push buttons and their relays. Normally-open contacts of RELAY OS close, energizing selector RELAY SR5. Closing the SR5 contacts in the torque-motor reference-field circuit applies voltage to this torque-motor field. Closing the OS relay contacts and the SR5 relay contacts in the torque-motor control-field circuit applies the voltage output of the OS Variac to the control field. When selector relay SR5 is energized, its normally-closed contacts open, de-energizing the by-pass solenoid on the hydraulic pump. Operation is similar for out-fast, in-slow, and in-fast operation. Operation of all other emergency rods is identical to operation of Rod No. 5.

4. Emergency-Rod System--Components

4a. Rack

Each of the sixteen racks is approximately 32 feet long made up of six sections each two inches square and 64 inches long. Lap joints backed up by a splice plate are used to hold the sections of rack together. The teeth have full-depth involute form, with 20-degree pressure angle and

ten diametral pitch. Machined in the two vertical sides of the rack near each end are slots which are engaged by the buffer stop if the rod should move beyond its normal limits of travel. Each rack is attached to its rod by means of a simple lap joint. Three dowel pins and six screws hold the two pieces firmly together.

4b. Rack Bearing Supports

Nine rack bearing supports are installed under each rack to support and guide it. These supports are secured to the structure and are spaced along the rack path, as shown in Figure 2.1. Each consists of a wedge-plate weldment, two leveling wedges, and a base casting which supports a bottom roller and two side rollers. The assembled support is shown in Figure 2.5 and a disassembled view is shown in Figure 2.30.

The plate weldment forms the base for the assembly and has two angles, each with two bolt slots, for the bolts which attach it to the structure. When the support is installed, shims are inserted between the angles and the structural channels to compensate for variations in structural dimensions. The vertical bolt slots in the angles, and similar horizontal slots in the structure channels, permit rough vertical and horizontal adjustment. Three leveling screws, with their lower ends bearing on the support structure, provide for precise leveling of the roller assembly. Fine vertical adjustment is accomplished by a matched pair of wedges under the base casting. During wedge adjustment the three aligning bolts prevent longitudinal movement of the casting. These bolts are also used to align the bottom-roller shaft at right angles with the rack centerline. The bottom roller is mounted on ball bearings, and the

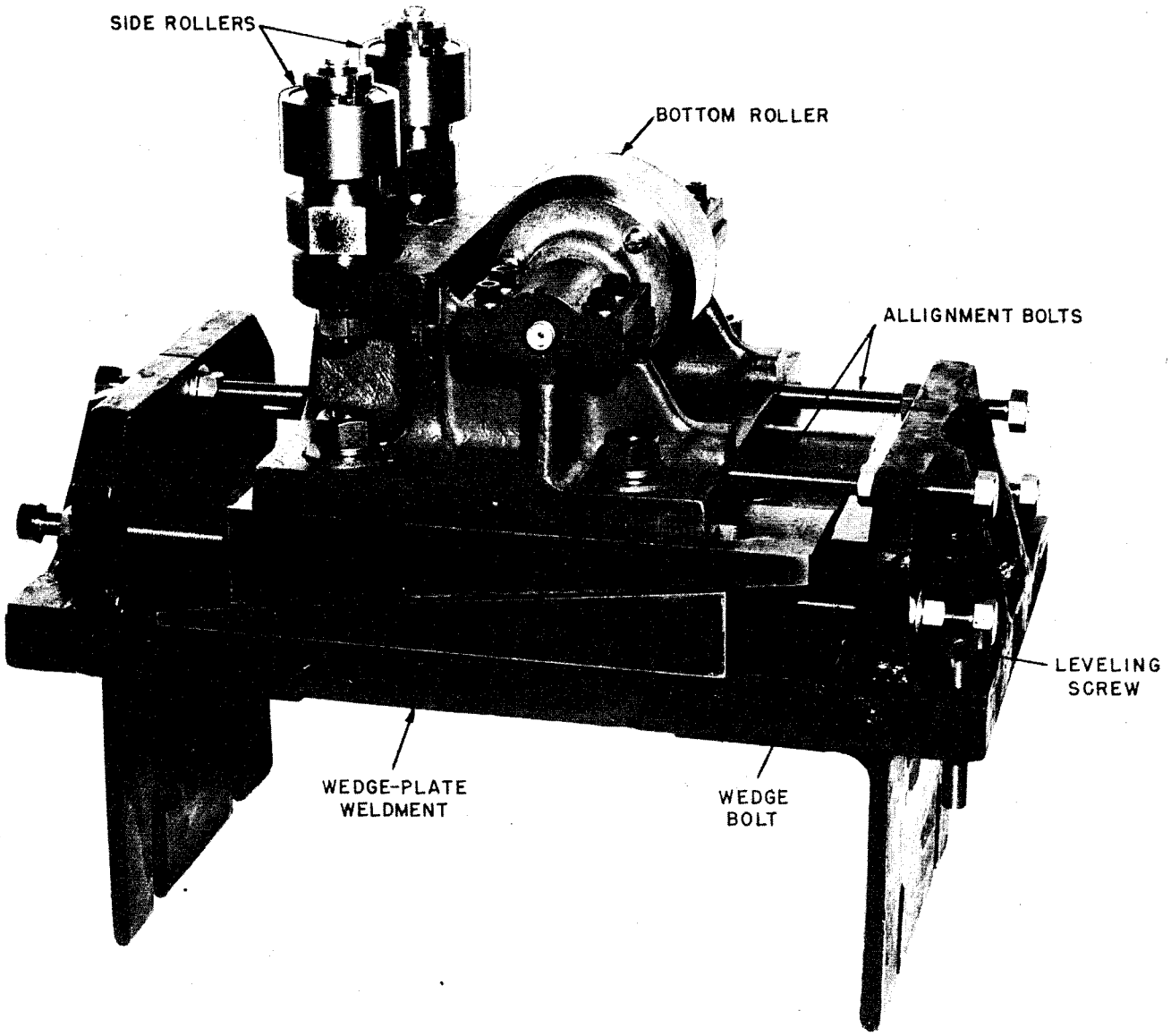


FIGURE 2.5 RACK BEARING SUPPORT

two side rollers on roller bearings which are carried on eccentric axles to permit fine transverse adjustment.

4c. Overtravel Stop

The overtravel stop, shown in Figure 2.6, prevents damage from overtravel of the rod in case the automatic stop devices are inoperative. On each of the emergency-rod drives, it also serves as a mounting for the drive pinion and its support rollers, and for the limit-stop pinion.

The overtravel stop consists of a box-like welded frame, a pair of slideways, a pair of stop-slide assemblies, two buffer springs, two spring plates, and a spring-guide arrangement. The slideways are bolted and doweled to the frame, and carry the stop-slide assemblies. The two stop-slide assemblies are similar, each consisting of a stop-slide weldment and the spring-loaded stop pawls, which engage the machined slots in the sides of the racks. When the rod is not in overtravel, the small rollers mounted in the pawls are forced against the rack by the pawl-loading spring, and the inside faces of the pawls are approximately parallel to the rack sides. When the rod approaches overtravel, the slots in the rack permit the pawls to move out, approximately as shown in Figure 2.6, and engage the bottoms of one pair of slots in the rack. The pawls pivot around pins in holes large enough to permit the end of the pawl which stays in the frame weldment to be pushed against a formed surface in the weldment. Hence, the pawl-pivot pins do not carry the force necessary to stop the rod. The two buffer springs are of the helical, compression type, one of them being

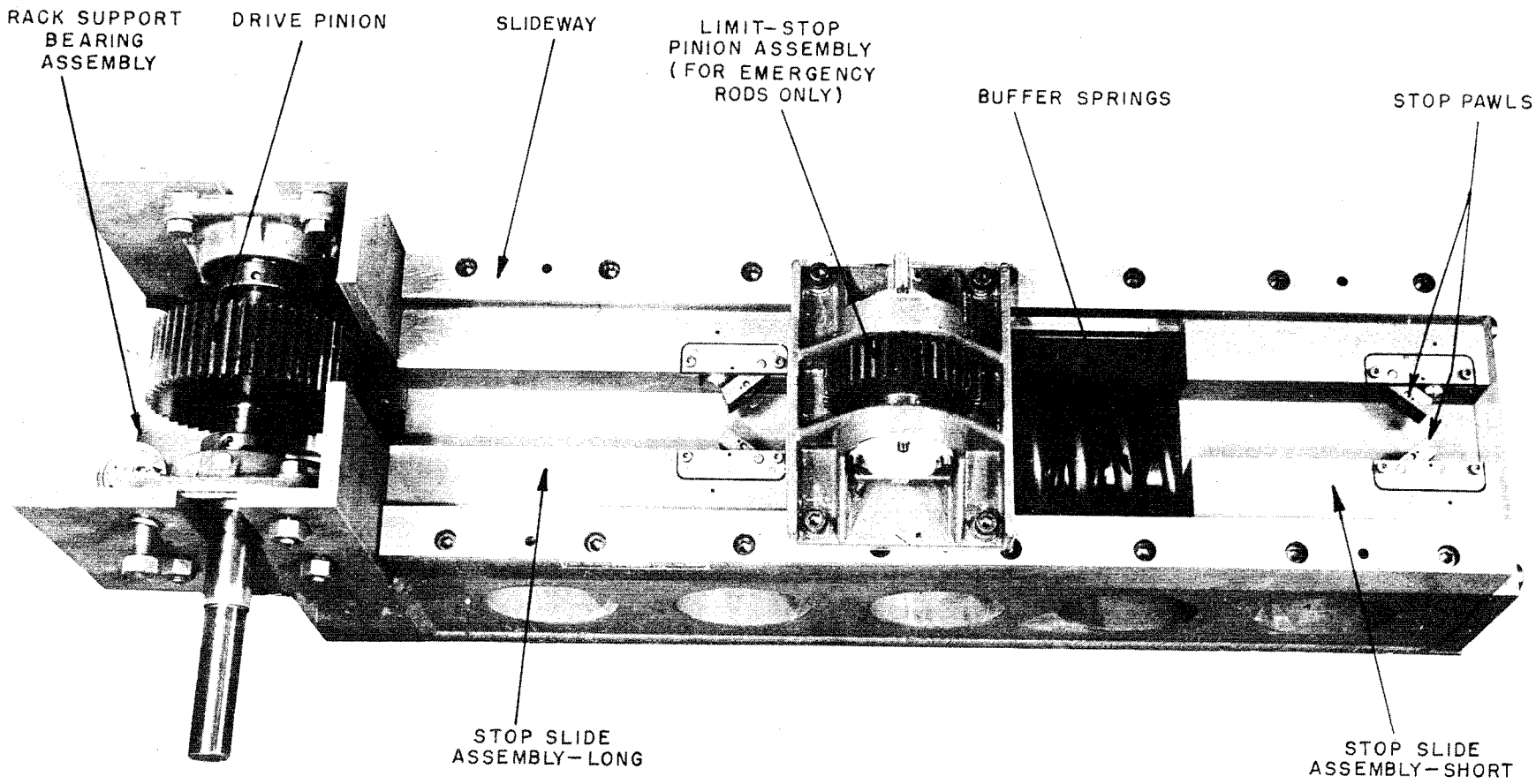


FIGURE 2.6 OVERTRAVEL STOP

large enough to fit over the other. They are guided by a telescoping tube and rod which fasten to the two spring plates against which the ends of the two springs bear. The lengths of the springs and welded frame are such that the springs normally press the stop-slide assemblies against the end plates of the frame with a preload of approximately one hundred pounds.

Action of the overtravel stop is as follows. The rollers on the pawls are initially against the flat sides of the rack. As the rod moves beyond the normal limit of travel, the rollers fall into the slots in the rod, permitting the free end of the pawl to move into the slots in the rod. When the ends of the slots engage the ends of the pawls, the stop-slide assembly begins to move, pushing its spring plate with it. As the spring is compressed, the load is transmitted through the spring and the stop-slide assembly not being moved, to the frame. The springs are capable of stopping an emergency rod traveling at 5.5 feet per second and opposed by maximum thrust of the emergency-rod drive in a distance of 10 1/2 inches.

4d. Drive Pinion

The drive pinion, which transmits power from the emergency-rod drive to the rack, is mounted at the end of the overtravel stop toward the reactor. The pinion has a face width of two inches. The teeth have full-depth involute form, with 20-degree pressure angle and ten diametral pitch.

This pinion is forged integrally with its shaft and is mounted in commercial ball-bearing pillow blocks, as shown in Figure 2.6. One

end of the shaft has a keyway for coupling to the drive mechanism. In the units for the emergency rods, the other end of the shaft carries an extension with a keyway to engage the hand crank. Immediately below the drive pinion on the overtravel-stop frame is mounted a rack-bearing support without the base weldment. This support assures proper mesh between rack and drive pinion. Slotted holes in the overtravel stop weldment permit adjustment of the bearing cartridges for proper pinion mesh with the rack. After adjustment, the setting is secured by dowels.

4e. Limit-Stop Pinion

A limit-stop pinion assembly is bolted to the overtravel stop for each of the emergency rods, as shown in Figure 2.6. The assembly, illustrated in Figure 2.7, includes a base casting, two roller bearings, and a pinion. The pinion has a one-inch face width with 40 teeth of 10 diametral pitch. Tooth form is full-depth involute with 20-degree pressure angle. The pinion shaft is splined for coupling to the shaft from the limit-stop mechanism.

4f. Hand Crank

A lever-and-ratchet mechanism, shown in Figure 2.8, provides for movement of the emergency rods in case the power drives are inactive. There are fourteen such cranks, one for each emergency rod. When not in use, each hand crank is stowed on a special bracket on the main girder near its power drive.

The crank consists of a lever arm carrying a ratchet wheel and a pawl. The length of the lever arm provides a mechanical advantage of approximately 6 to 1. The ratchet is bored to fit over the extension

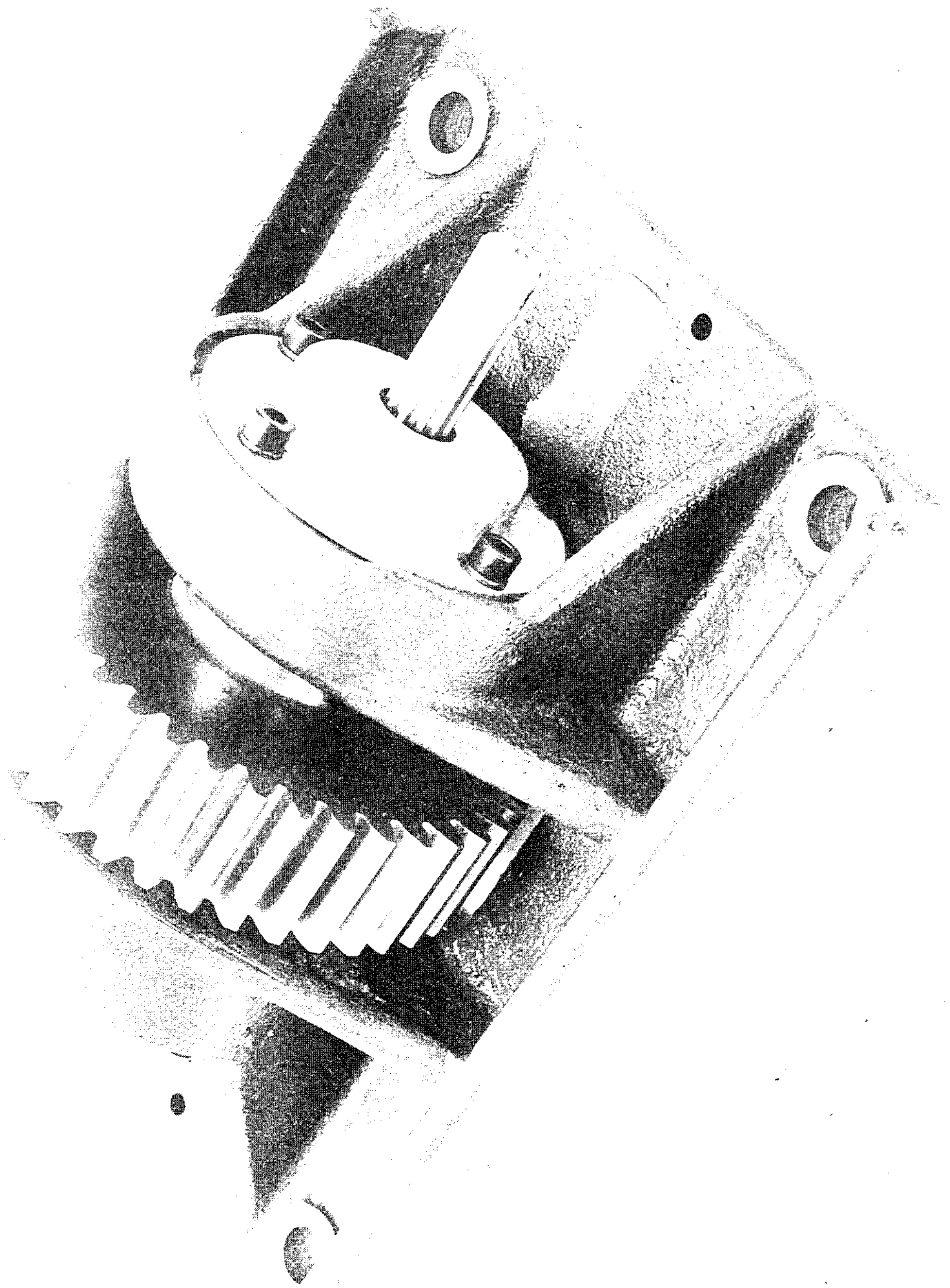


FIGURE 2.7 LIMIT-STOP PINION

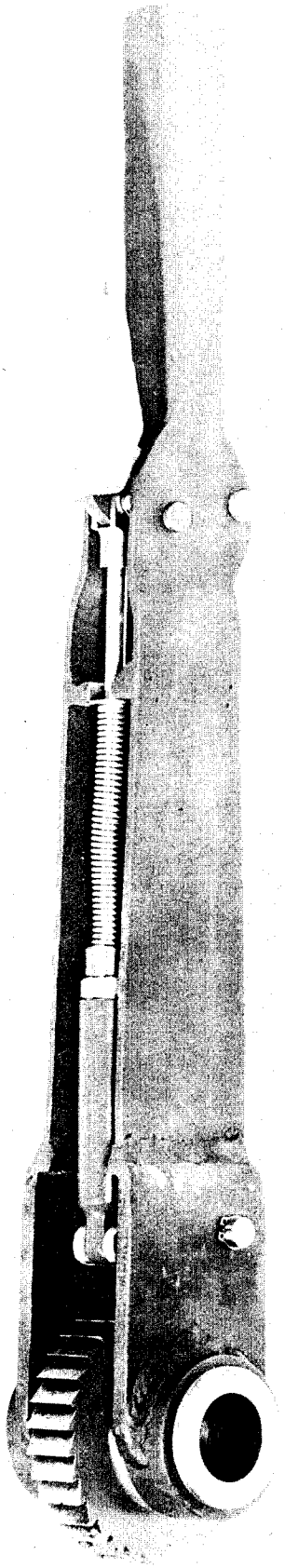


FIGURE 2.8 HAND CRANK

on the shaft of the drive pinion. A key fixed in the ratchet bore engages a keyway in the shaft. The pawl is held out of engagement by a "deadman" spring unless a grip on the lever arm handle is grasped.

4g. Emergency Drive Unit

This unit consists of a hydraulic motor and a speed reducer coupled by a flexible coupling and mounted on a base weldment as shown in Figure 2.9. Maximum torque at the output of the speed reducer is approximately 125 foot-pounds, which produces a 600-pound thrust on the rack. Maximum speed of the output shaft is approximately 250 rpm, which produces a maximum rack speed of approximately 5.5 feet per second. The emergency drive units are bolted to the control-rod structure in the locations shown in Figure 2.1.

The speed reducer is a commercial unit (Philadelphia Gear Works, Size 3103, Type LX) having a speed reduction of 3.36 to 1. It has an intermittent torque rating of 475 inch-pounds at the input shaft.

The hydraulic motor is a commercial, constant-displacement, eleven-piston motor (The Oilgear Company Type H-811) of the axial-piston type. In this type of motor, output speed is proportional to rate of oil supplied (neglecting leakage) and output torque is proportional to pressure drop across the pump. Output shaft rotation can be reversed by reversing the direction of oil flow. The motor has a displacement of 1.914 cubic inches per revolution. Its peak torque rating is 480 inch-pounds at 1650 pounds per square inch. When driven by the pumping unit used in this application, it will develop a maximum speed of approximately 940 rpm.

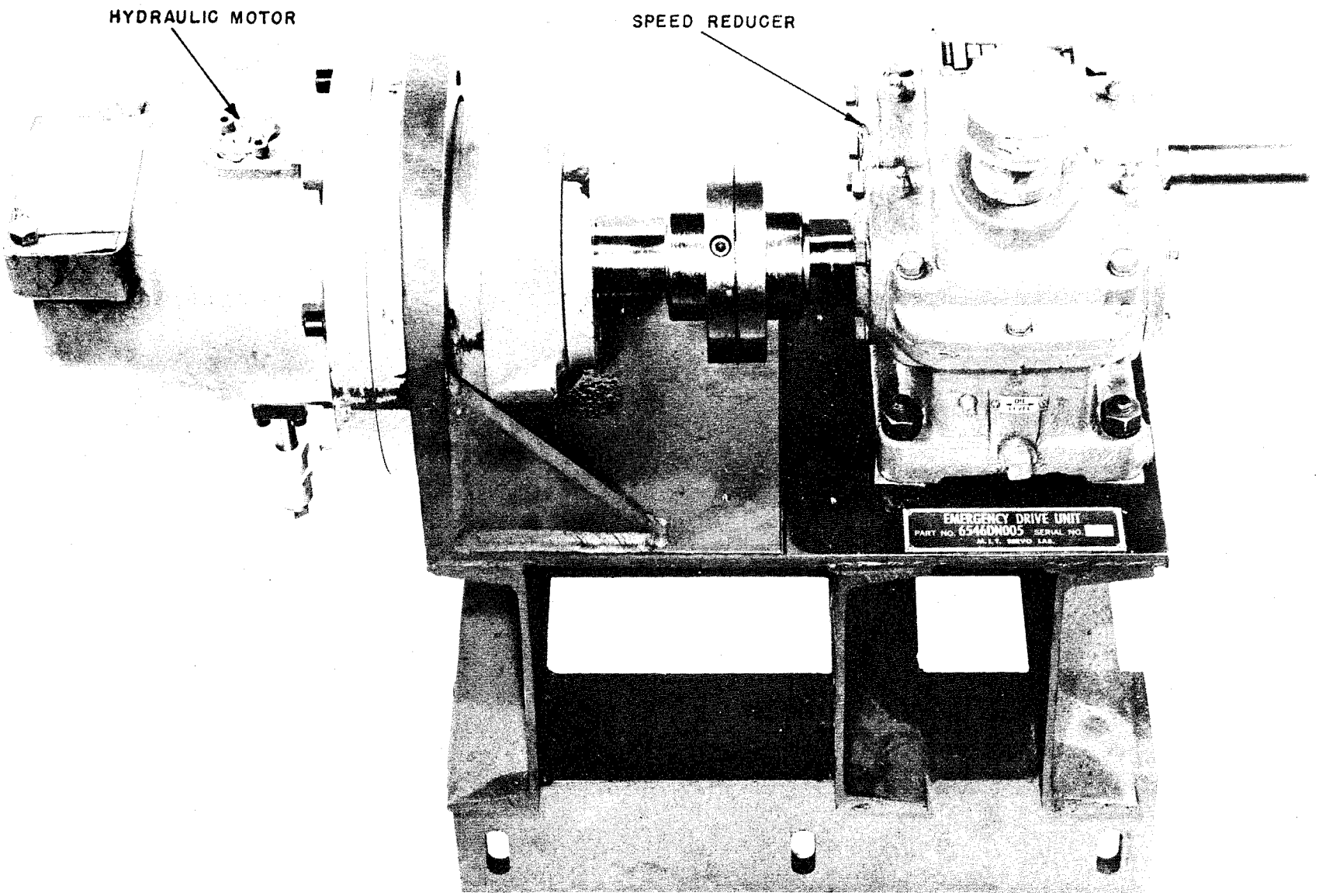


FIGURE 2.9 EMERGENCY DRIVE UNIT

4h. Emergency-Pump Assembly

Each emergency drive unit receives power from its emergency-pump assembly. The hydraulic motor of the emergency drive unit and the pump of the emergency-pump assembly comprise a variable speed, reversible, hydraulic transmission. The transmission is powered by an electric motor and provided with a flywheel to supply enough energy to insert the emergency rod in case electric power fails. All fourteen pump assemblies are identical except for the piping between hydraulic pump and motor, and the gear train in the limit-stop mechanism. Eight of these items are right-handed and six are left-handed. Otherwise they are identical. The emergency-pump assembly consists of the electric motor, flywheel, and pump mentioned above, mounted on a base weldment with their associated stroke control, limit-stop mechanism, tachometer generator, pressure switch and pressure gauge. An assembly is shown in Figure 2.10.

The hydraulic pump is a modification of the Type AH311 variable-delivery, radial-piston pump manufactured by The Oilgear Company. Delivery of the pump is varied by changing the stroke of the pistons. Piston stroke is controlled by the position of the stroke ring against which the outer ends of the pistons bear. Pump delivery can be varied continuously from zero to maximum for either direction of oil flow through the pump. The modified pump has a maximum displacement of 1.03 cubic inches per revolution, is driven at 1765 rpm, and has a continuous rating of 1100 psi. It is equipped with roller bearings on the slide block to reduce slide-block stroking force. Piping between the pump and motor is of stainless steel.

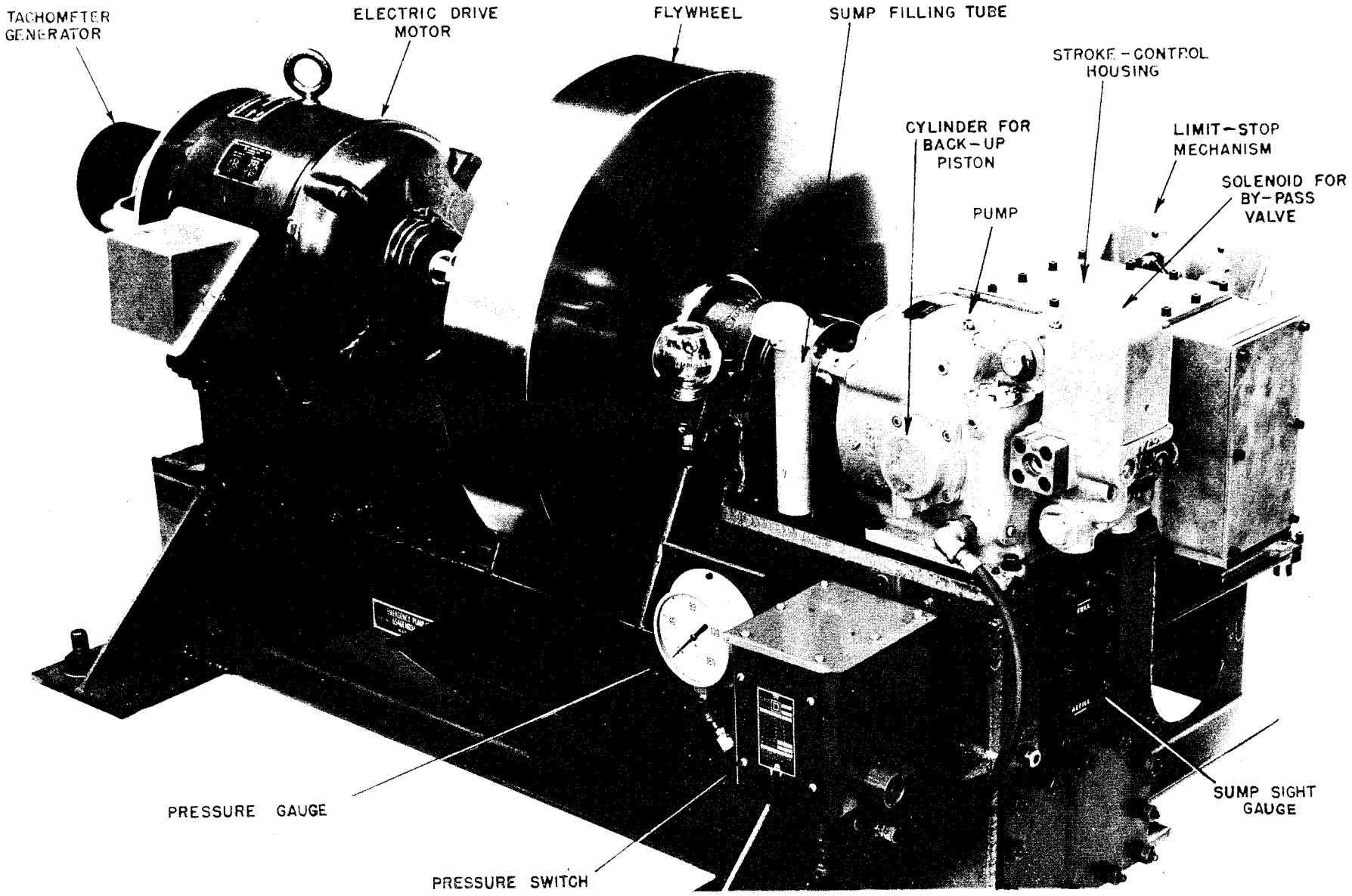


FIGURE 2.10 EMERGENCY PUMP ASSEMBLY

Flange-type ends are silver soldered to the tubes. The sealing elements are neoprene O-rings.

The auxiliary and control devices connected to the pump are shown schematically in the oil circuit diagram of Figure 2.11. Included in the main-pump housing are the gear pump, the pressure regulator valve, the filter, the replenishing check valves, the high-pressure relief valve, and the by-pass valve. Mounted on the sides of the pump are the stroke control and back-up piston which together control the stroke of the main pump, and thus the speed of the hydraulic motor in the emergency-drive unit. Mounted on the base weldment of the emergency pump assembly are the pressure gauge and pressure switch.

The sump, not shown in Figure 2.11, is a reservoir in the base weldment, of approximately 6-1/2 gallons capacity, into which all leakage is discharged and from which is pumped all oil for the main hydraulic system and the control system. A sight gauge is provided for ease in checking oil level.

The gear pump delivers oil from the sump, under pressure, to the control and the replenishing systems. This gear pump has a displacement of 0.49 cubic inches per revolution, and, consequently, a delivery of 857 cubic inches per minute when the pump is being driven at normal operating speed. The gears of this pump are helical to provide quiet operation. One gear of the pump is driven directly by the main-pump shaft.

The pressure of the oil delivered by the gear pump is controlled by the replenishing pressure regulator. This regulator is set to maintain a pressure of approximately 100 psi. Excess oil from the gear pump is returned to the sump.

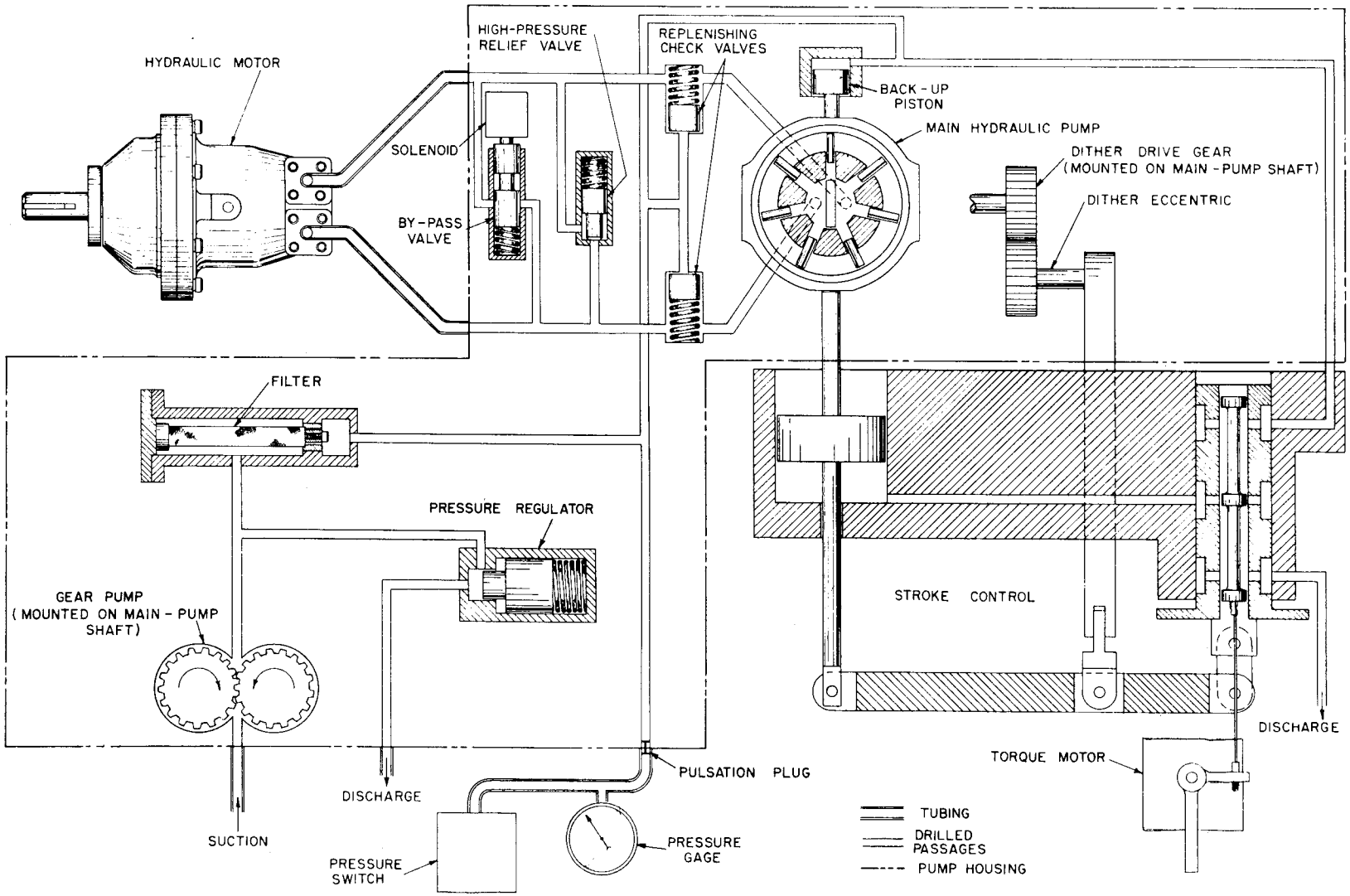


FIGURE 2.11 OIL CIRCUIT FOR EMERGENCY-ROD DRIVE

All oil used for replenishing and stroke control passes through the filter to prevent pieces of extraneous matter from harming accurately machined parts. This filter element, of the wire-wound type having 0.0015-inch spacing between wires, is manufactured by Purolator Company. (No. 22924PH, 3 1/2 inches long, 15/16 inch diameter.)

Oil leaking from the main pump and hydraulic motor is resupplied by oil flowing through the replenishing check valves. Either of these valves will open to permit oil at 100 psi to flow to the high-pressure oil line to which it is connected, but will close when the pressure in the high-pressure line exceeds 100 psi. This arrangement prevents cavitation of the oil in the high-pressure system and forces the pistons of the hydraulic motor against their thrust bearing.

The high-pressure relief valve and the by-pass valve are connected across the high-pressure lines of the pump. The high-pressure relief valve is double acting, and is set by the preload in its spring to permit high-pressure oil to flow from one line to the other when the pressure in either line exceeds 1750 psi. This relief valve, by limiting the maximum pressure delivered by the pump, acts as a torque-limiting device for the hydraulic motor, thus preventing damage to the equipment driven by the motor, as well as preventing damage to the pump and motor themselves.

Because it is impossible to hold the pump displacement exactly at zero for protracted periods of time, a spring-loaded, solenoid-operated by-pass valve is placed across the high-pressure pump lines.

When no motion of the rod is desired, the solenoid is energized, and the valve by-passes the small quantity of oil which may be delivered by the pump. When the rod is to be moved, the solenoid is de-energized, and the by-pass is blocked, forcing the entire pump delivery to pass through the hydraulic motor. However, the by-pass is small enough to permit the pump to develop full 1650 pounds pressure in the rod-in direction, even if the by-pass valve should fail to close.

A pressure gauge indicates replenishing pressure at all times.

A pressure switch monitors oil pressure in the replenishing system continuously. This switch is connected to the emergency-shutdown system and is set to close at approximately 80 psi and open at approximately 60 psi. It is a Class 9013, Type ASW-1DPR pressure switch manufactured by Square-D Company, and comes equipped with an oil-resisting diaphragm and a pulsation plug.

The stroke control, shown schematically in Figure 2.12 and pictorially in Figure 2.13, controls the delivery of the main pump. Components of the stroke control are enclosed in a housing attached to the main-pump housing. A separate housing encloses the limit-stop assembly from which a connecting shaft enters the stroke-control housing. The main components of the stroke control are a torque motor, a hydraulic amplifier, and an emergency-shutdown solenoid. The torque motor, acting in response to signals from the operator's console, causes the amplifier to put the hydraulic pump on zero (neutral), small, or medium stroke. The solenoid, in response to a signal from the emergency-shutdown system, causes the amplifier to put the pump on full stroke to insert the rod.

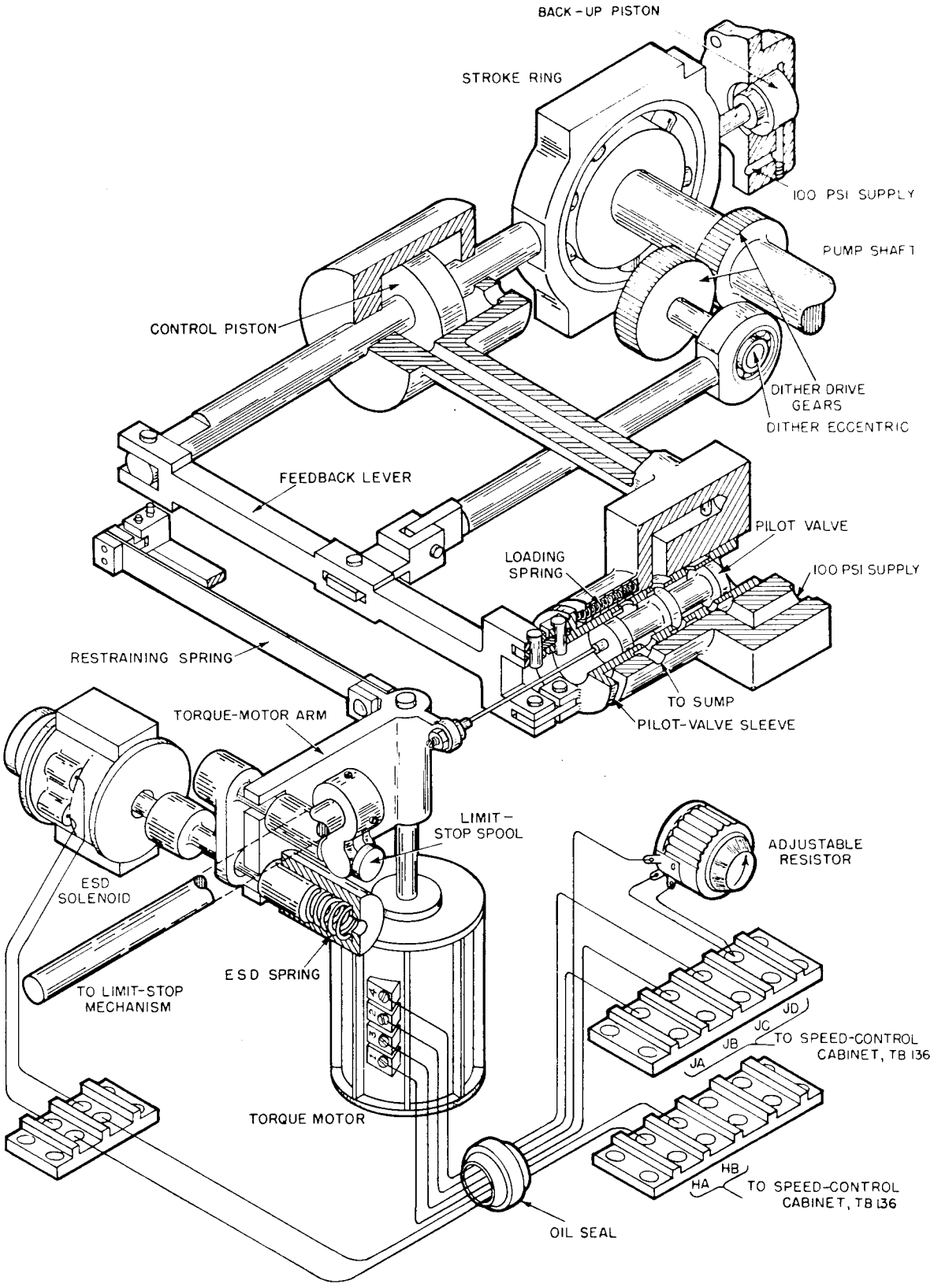


FIGURE 2.12 STROKE-CONTROL MECHANISM

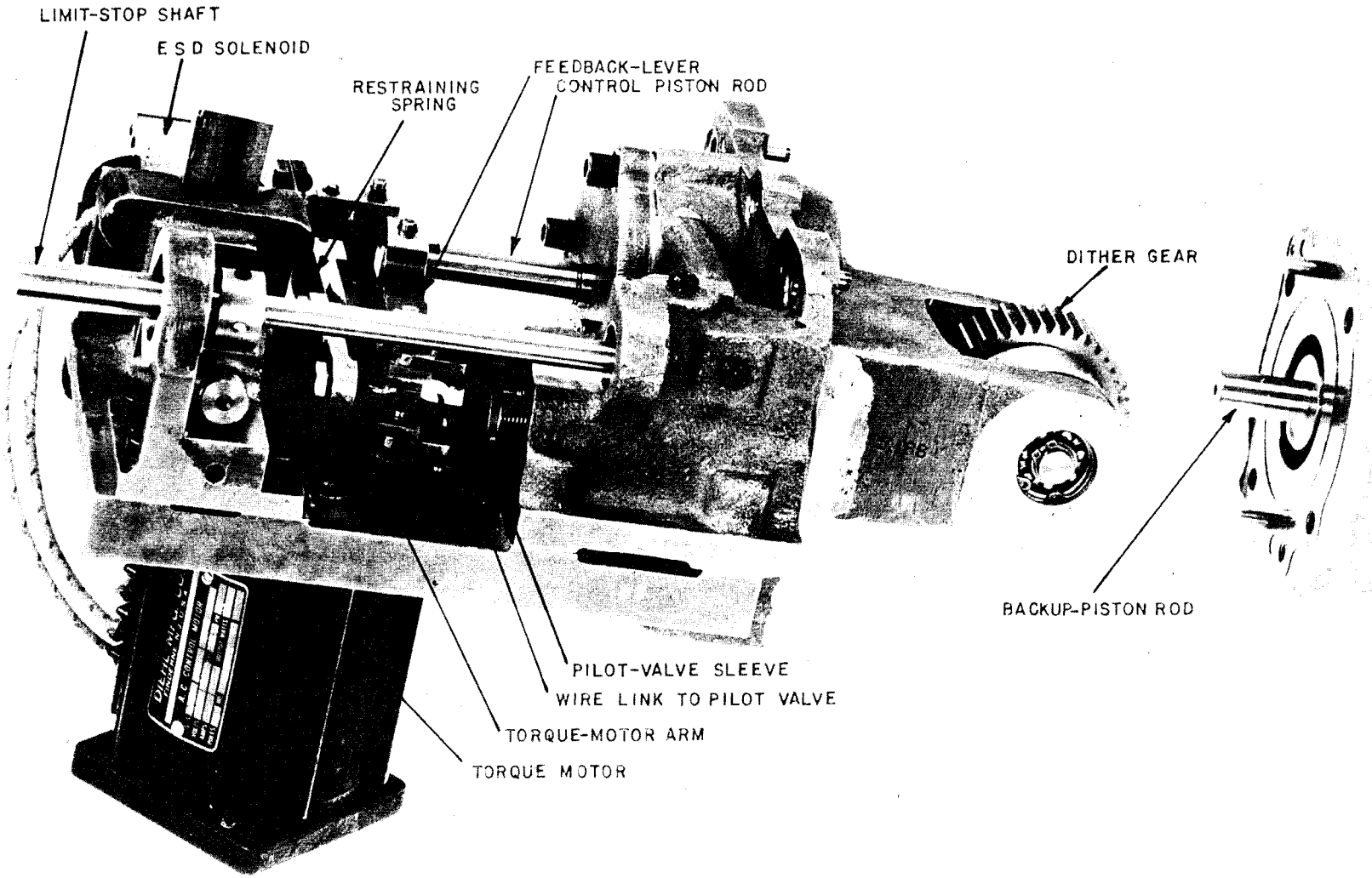


FIGURE 2.13 EMERGENCY-ROD DRIVE - STROKE CONTROL

2.31

The torque motor is a two-phase control motor (Diehl type 49-10-2) capable of producing a torque of 24 inch-ounces. The control field is supplied by an adjustable voltage, through Variacs, from the push buttons on the console. The reference field is supplied through a variable resistor (250 ohms maximum) which can be adjusted to assure the same speed of all fourteen rods for the same applied voltage on the fourteen torque-motor control fields. A calibrated restraining spring resists rotation of the torque-motor rotor, and returns it to neutral when the fields are de-energized. A wire link converts rotation of the rotor to linear motion of the pilot valve.

The hydraulic amplifier includes a backup piston, a control piston, a pilot valve and valve sleeve, a feedback lever, and a dither mechanism. The two pistons are arranged to exert opposing forces on the stroke ring of the pump. The oil on the inner sides of both pistons is ported to the sump. Oil at 100 psi is ported to the outer face of the backup piston, while the oil pressure on the opposing face of the control piston is regulated by the pilot valve. The control piston area is twice that of the backup piston.

The pilot valve and sleeve compose a three-way valve, the center land of the valve being the operating part. This land has a positive lap of 0.010 inch to make certain that the port in the sleeve closes. It is surrounded by the pilot-valve sleeve which is connected through the feedback lever to the control-piston rod. Oil at 100 psi is ported to the inner side of the pilot-valve land, while the oil on the outer side of the land is ported to the sump.

Operation of the mechanism is initiated by rotation of the torque motor. The direction and magnitude of this rotation is determined by the push button selected by the operator. If the motor turns clockwise, the pilot valve moves outward porting oil at 100 psi to the control piston. This pressure forces the control piston inward against the same pressure on the smaller area of the backup piston. The resulting stroke-ring displacement puts the pump on stroke to drive the hydraulic motor in the direction for inward rod travel. At the same time the feedback lever moves the pilot-valve sleeve outward to close the port. Thus, control-piston displacement is proportional to that of the pilot valve.

Counterclockwise rotation of the torque motor moves the pilot valve inward, porting the oil in the control-piston cylinder to the sump. The pressure on the backup piston can then move the stroke ring outward, reversing the pump delivery and driving the rod out of the reactor.

The dither mechanism consists of a driving gear on the pump shaft, a driven gear on the same shaft with the dither eccentric, and a dither rod and link, one end of which is the feedback-lever fulcrum. The mechanism imparts a vibratory motion of small amplitude to the pilot-valve sleeve to eliminate starting friction between the pilot valve and sleeve. The amplitude of the vibration at the sleeve is not sufficient to port oil to the control piston.

The emergency-shutdown solenoid is normally energized and holds its plunger out against the ESD spring. For emergency shutdown, the solenoid is de-energized, the spring forces the plunger in, and the

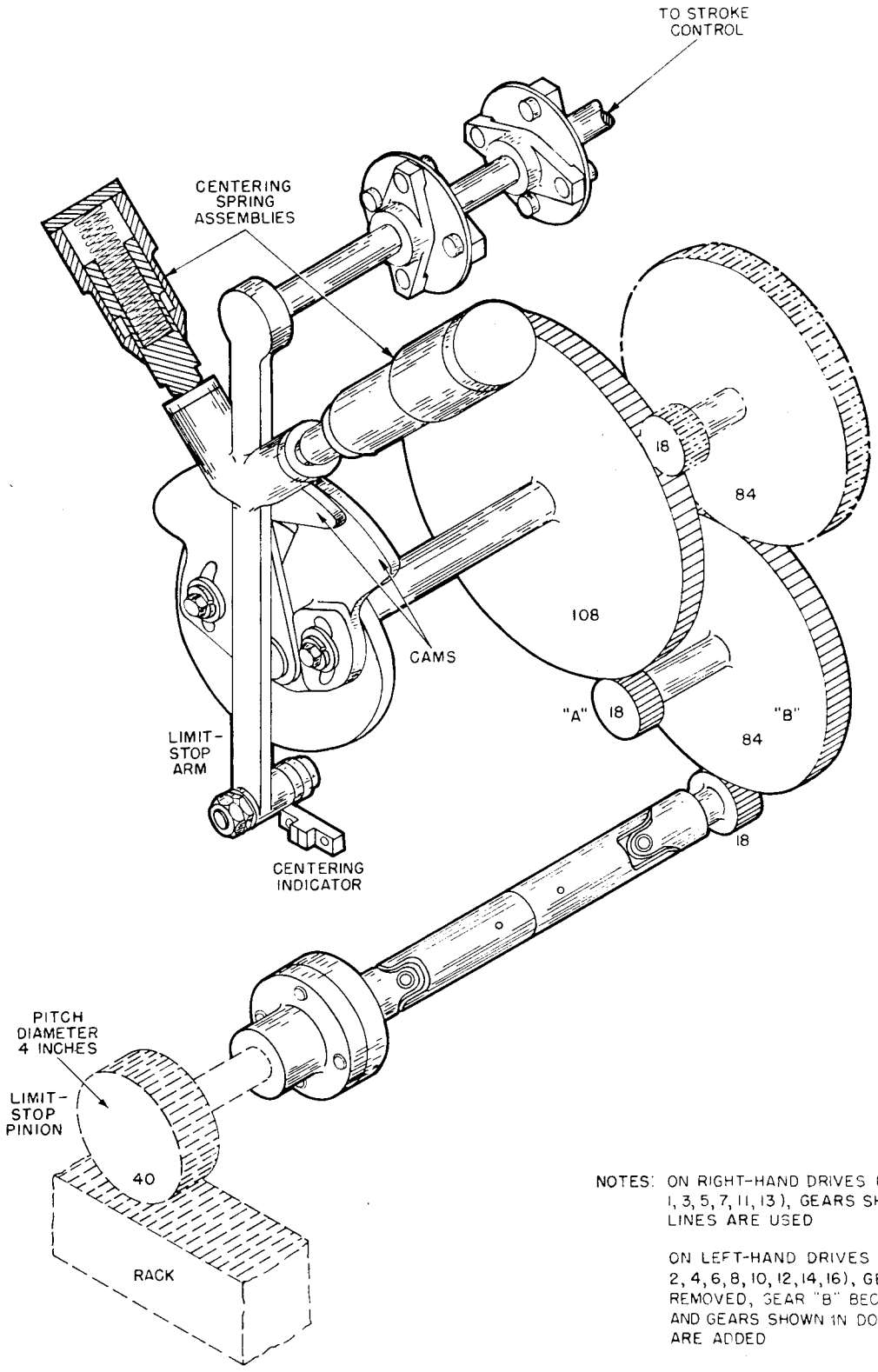
lug on the plunger rod moves the torque-motor arm clockwise far enough to cause the rod to be inserted at full speed.

The limit-stop mechanism, shown schematically in Figure 2.14 and pictorially in Figure 2.15, includes a gear train, two cams, and a limit-stop arm and its shaft, all enclosed in a housing mounted adjacent to the stroke-control housing. Additional components, the limit-stop spool with its pusher rod, and an extension of the shaft of the limit-stop arm, are in the stroke control housing, as shown in Figure 2.12.

The mechanism is driven from the rack by the limit-stop pinion. Commercial gears of twenty diametral pitch and 3/8-inch face width are used throughout. The variation in the gear trains, as noted in Figure 2.14, permits use of otherwise identical stroke-control mechanisms for both right and left-hand drives. Pinion rotation is transmitted to a cam plate through a pair of universal joints and the gear train. The two centering spring assemblies keep the arm at its center, or neutral, position when the cams are free from the follower.

A forked crank (Figure 2.12) engages the limit-stop spool and converts rotation of the shaft from the limit-stop arm to linear motion of a push rod, which, in turn, moves the torque-motor arm. There is sufficient lost motion between the push rod and the torque-motor arm to allow normal operation by the torque motor or the emergency-shutdown solenoid.

Contact of either cam with the follower moves the limit-stop spool, first to take up the lost motion, and then to return the torque-motor arm to neutral and stop rod travel. The gear ratios, linkages, and lost motion are so proportioned that, with the rod traveling at



NOTES: ON RIGHT-HAND DRIVES (RODS NOS 1, 3, 5, 7, 11, 13), GEARS SHOWN IN FULL LINES ARE USED

ON LEFT-HAND DRIVES (ROD NOS. 2, 4, 6, 8, 10, 12, 14, 16), GEAR "A" IS REMOVED, GEAR "B" BECOMES AN IDLER, AND GEARS SHOWN IN DOT-DASH LINE ARE ADDED

NUMBERS ON GEARS DESIGNATE NUMBER OF TEETH

FIGURE 2.14 LIMIT-STOP MECHANISM FOR EMERGENCY-ROD DRIVE

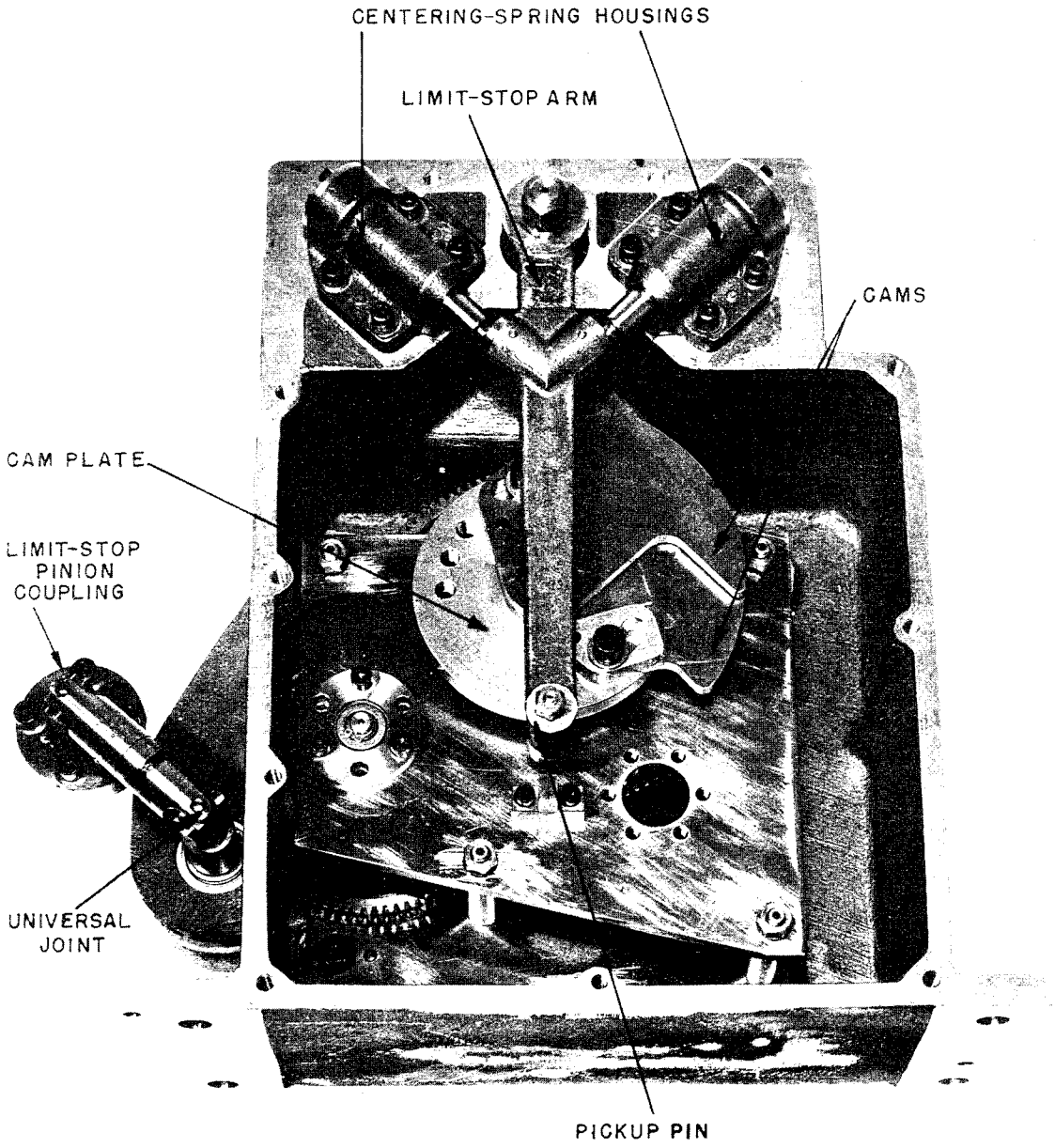


FIGURE 2.15 LIMIT-STOP MECHANISM

maximum speed, deceleration begins at approximately two feet from the point at which it is finally stopped. Since displacement of the torque motor arm is proportional to rod speed, the lost motion at slower speeds is greater. Thus, the beginning of deceleration is correspondingly nearer the limit of travel.

The range of cam adjustment is such that rod travel can be limited, at either end, to any point within six feet of the maximum design limit. Alternate cams are provided by which the outward travel can be stopped at any point between six and twelve feet from the maximum limit.

The flywheel assembly, shown in Figure 2.16, consists of a base casting, two self-aligning sleeve bearings, and a solid disc flywheel forged integrally with its shaft. The base casting is supported on the base of the pump assembly. The flywheel shaft is directly coupled, at one end to the electric drive-motor shaft and at the other end to the pump shaft (see Figure 2.10).

The two pedestals supporting the bearings are hollow to form lubricating oil reservoirs. Each reservoir is equipped with a modified commercial constant-level oil control to maintain the oil level in the reservoir within 1/64 inch. Oil discs, secured to the shaft, carry oil to the bearings. The bearings are carried in spherical bearing holders to provide for self-alignment.

The flywheel is a solid disc twenty-one inches in diameter and 4 1/2 inches in face width. The total rotating weight is approximately 465 pounds, which stores approximately 93,000 foot-pounds of energy at 1765 revolutions per minute.

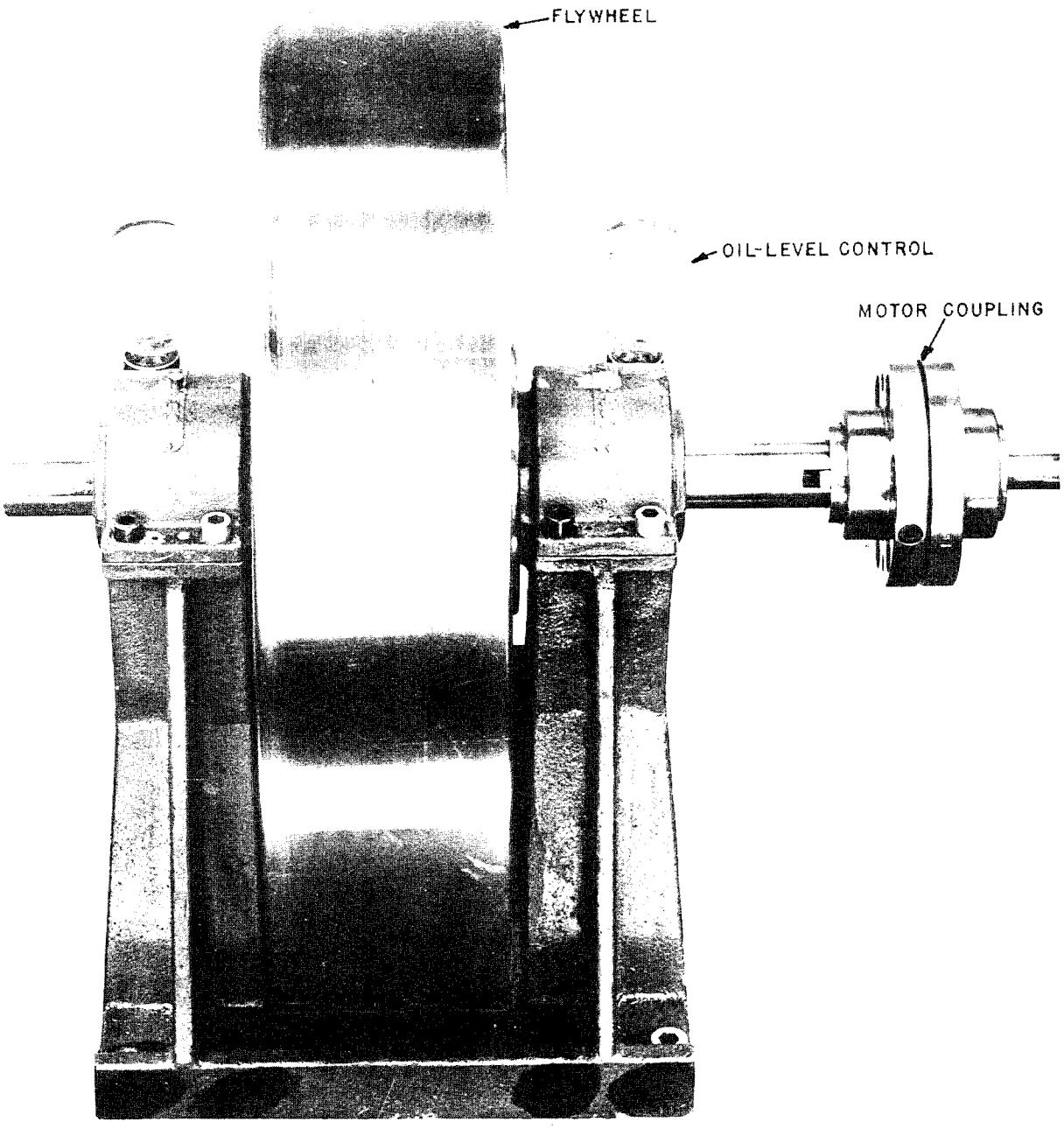


FIGURE 2.16 FLYWHEEL ASSEMBLY

A guard assembly, consisting of a top-cover weldment and two leg weldments, encloses the wheel. Suitable sheet-metal guards cover the rotating shaft couplings.

The electric drive motor is a commercial, 3 h.p., three-phase, 220/440-volt, 1740 rpm, Code J, Model SC225JA4-3, induction motor manufactured by the Century Electric Company. It is a standard, sleeve-bearing motor with a low starting-current characteristic to prevent damage to the windings during the protracted starting time required to accelerate the flywheel. Special machining of the rear-end bell was required to mount the tachometer bracket. To provide a shaft extension to drive the tachometer, the rear end of the motor shaft was tapped, and a threaded shaft extension inserted.

The tachometer generator is directly driven by the drive motor through a flexible coupling. It is a Westinghouse Type A-80 induction generator supported by a bracket attached to the motor. The tachometer indicators, Westinghouse Type K24, are mounted on section five of Control Panel M in the control room. They are designated M13 to M20, M22 to M26, and M28, inclusive. M21 and M27 are spare indicators.

4i. Control Equipment for Drive Motors

The motor control centers, P19 and P20, are manufactured by Cutler-Hammer. Equipment in them which controls the emergency-drive motors is as follows:

Air Circuit Breaker—Frame size 100A, trip unit 25 amperes.

Magnetic Switches--Size one contactor, 27.5- to 30.5-ampere overload element, two normally open auxiliary contacts, 115-volt closing coil.

Magnetic Switches—Size one contactor, 3.95- to 4.33-ampere overload element, two normally open auxiliary contacts, 115-volt closing coil.

Control Voltage Transformer—460:115 volts, one supplied with each combination starter.

Auxiliary Relay—115-volt closing coil, one normally closed and one normally open contact, rated 10-ampere make and 2-ampere break at 115 volts a-c.

5. Regulating-Rod System—Rod No. 9—General Description

Regulating Rod No. 9 is moved into and out of the reactor in response to signals from the console in the control room. Because it is used for accurate control of reactor power, this rod can be driven at very slow speeds. In the event of emergency shutdown, if electric power is still available Rod No. 9 is inserted at high speed.

The system used to control Rod No. 9 is shown schematically in Figure 2.17. Rod, rack, rack-bearing supports, overtravel stop, and drive pinion are the same as those used on the emergency rods. The drive pinion, however, is driven through a pair of change gears and a slip-clutch by the output shaft of a differential. The differential is driven by either, or both, of two electric motors through worm-type speed reducers. One motor is used for high-speed rod motion, and the other for low. Because low-pitch worms are used in the reducers, it is impossible to rotate the electric motors by rotating the reducer output shafts. During emergency shutdown, both motors operate to insert the rod as fast as possible.

The electric motors are controlled by two reversing-type motor controllers in the motor-control center. A set of four push buttons on the right side of the console skirt is used to control motion of the rod in or out at fast or slow speed. The rod moves as long as one of the

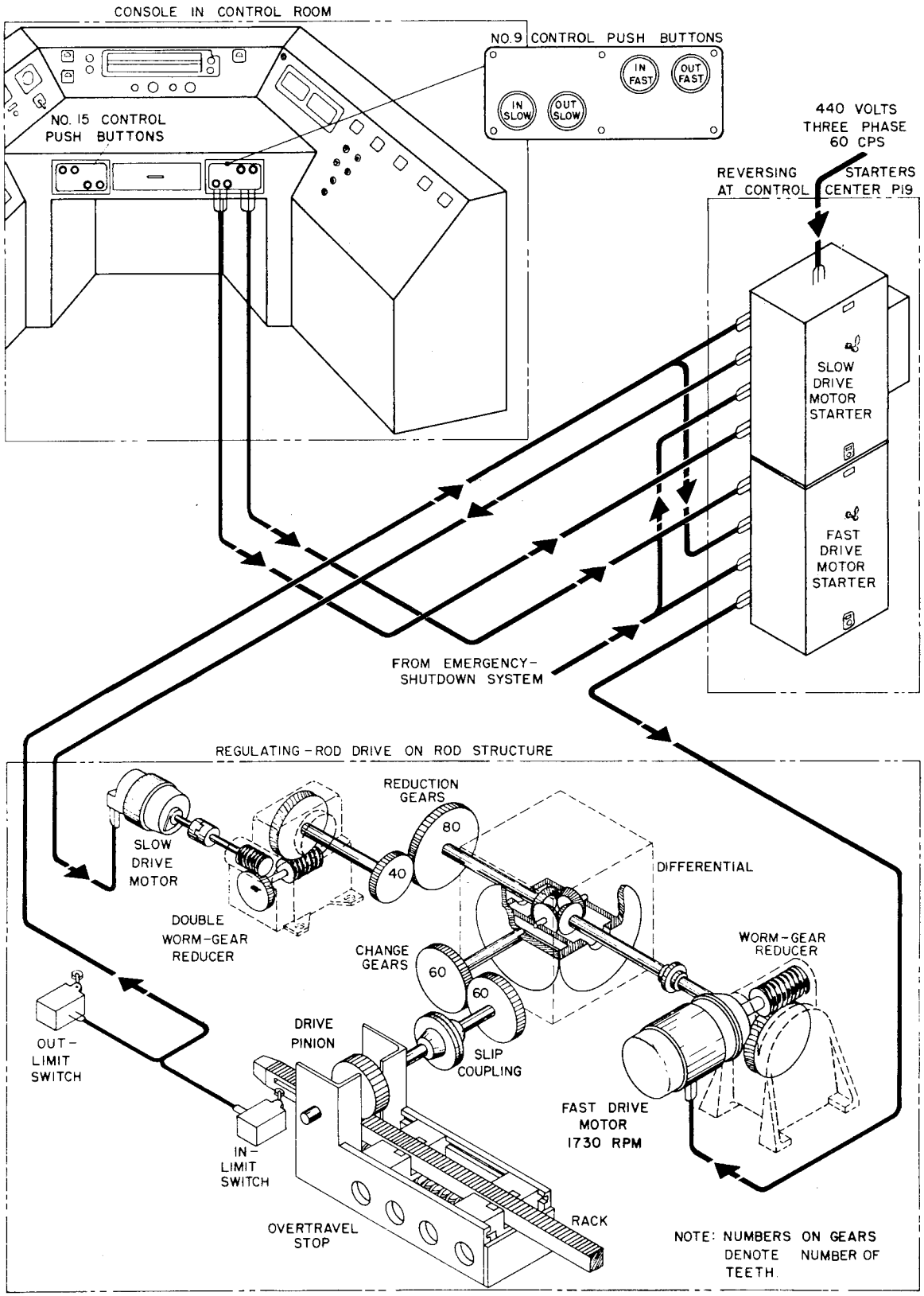


FIGURE 2.17 REGULATING - ROD SYSTEM ROD NO. 9

buttons is depressed unless it has reached one of its limits of travel. Two limit switches mounted at the rod structure are actuated by the end of the rack. These switches are connected in the control circuits of the motor controllers so that the motors can not drive the rod beyond its safe limits of travel. To prevent excessive coasting of the high-speed drive motor after power has been disconnected, a pair of time-delay plugging switches, located at the motor-control center, are used. The time delays are set to plug the motor approximately to standstill. The slip clutch between the change gears and the drive pinion is set at 1800 inch-pounds, making the maximum thrust at the rod 720 pounds. Rod speeds with the change gears supplied are given in the table below:

			High Speed		Low Speed	
Teeth on Driving Gear (Diff.)	Teeth on Driven Gear (Slip Clutch)	Gear Ratio	In. Per Sec	mm Per Sec	In. Per Sec	mm Per Sec
60	60	1:1	5.26	134	0.0603	1.53
48	72	1.5:1	3.51	89.1	0.0402	1.02
36	84	2.33:1	2.25	57.3	0.0258	0.656
24	96	4:1	1.31	33.4	0.0151	0.384

These speeds are based on rated full-load speeds of the induction motors.

6. Regulating-Rod System—Rod No. 9—Operation

Figure 2.18 shows the motor-control circuit for Rod No. 9. The electric motors and the limit switches are located at the rod structure, the push buttons are located on the console, and the remainder of the equipment is located in Motor-Control Center, P19. Power is supplied

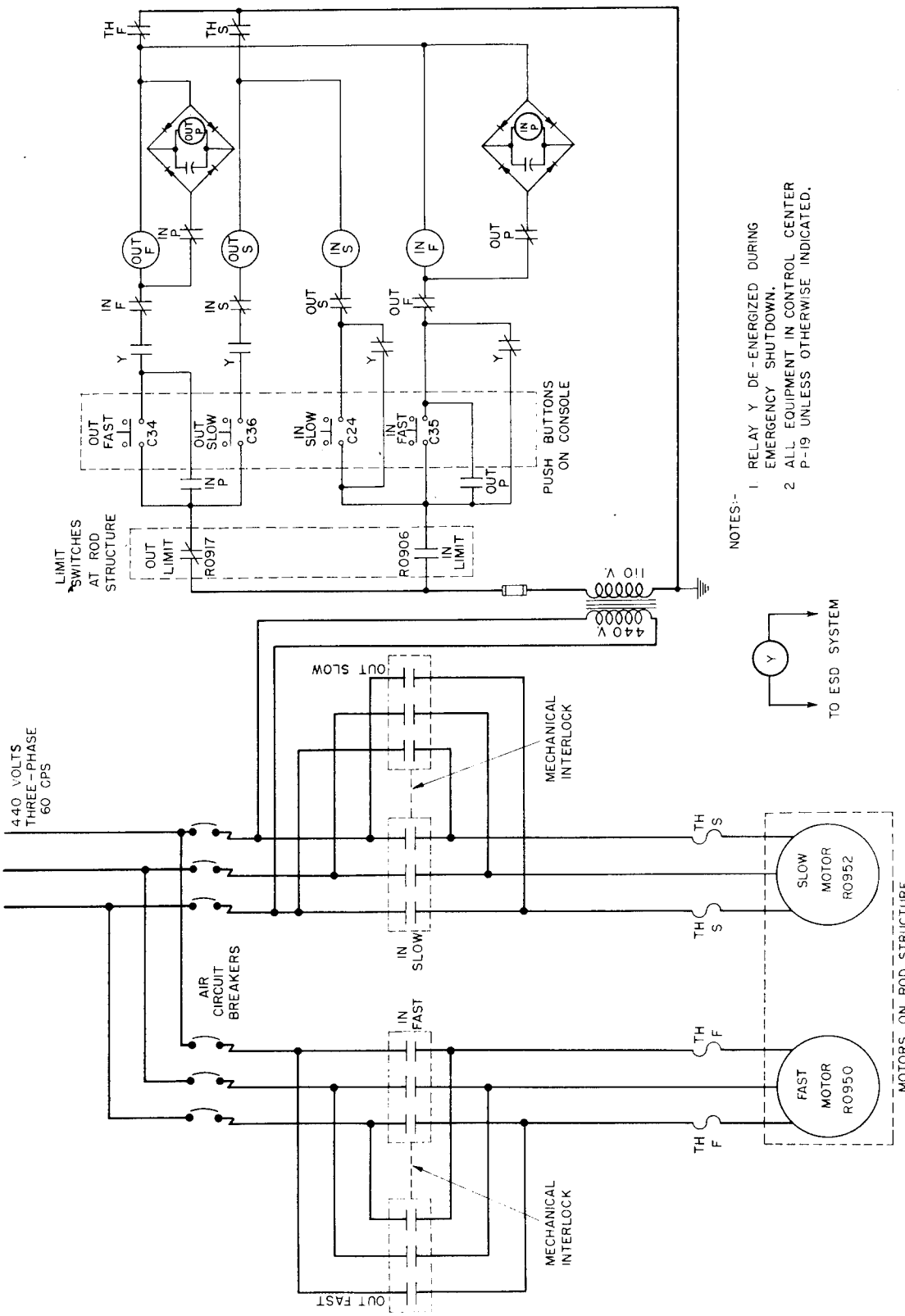


FIGURE 2.18 MOTOR-CONTROL CIRCUIT FOR ROD NO.9

to the electric motors through a pair of air circuit breakers and a pair of reversing contactors. The control circuit is energized through a 440/110-volt transformer. When the rod is in its normal operating range, the roller of the in-limit switch is against the rack, holding the switch contacts closed, and the roller of the out-limit switch is free, holding its contacts closed also. Since RELAY Y is energized except during emergency shutdown, its normally-open contacts are closed and its normally-closed contacts are open when the rod is controlled by the operator.

If the rod is in its normal operating range and there is no emergency-shutdown signal, operation of the control circuit is as follows. Depressing the OUT-SLOW PUSH BUTTON on the console energizes the coil of the OUT-SLOW CONTACTOR through the OUT-LIMIT SWITCH, the contact of RELAY Y, the auxiliary contact on the IN-SLOW CONTACTOR, and the SLOW THERMAL-OVERLOAD SWITCH. The line contactor to the slow-speed drive motor closes and the rod is withdrawn as long as the push button is depressed.

Depressing the IN-SLOW PUSH BUTTON while the OUT-SLOW PUSH BUTTON is depressed has no effect, because auxiliary contacts on the OUT-SLOW CONTACTOR open the OUT-SLOW PUSH BUTTON circuit. Moreover, the IN-SLOW and OUT-SLOW CONTACTORS are mechanically interlocked so that only one set can be closed.

When the OUT-SLOW PUSH BUTTON is released and the IN-SLOW PUSH BUTTON is depressed, the rod is inserted through operation similar to that described above.

Depressing the OUT-FAST PUSH BUTTON energizes the coil of the OUT-FAST CONTACTOR through the OUT-LIMIT SWITCH, the contacts on RELAY Y, the auxiliary contacts on the IN-FAST CONTACTOR and the FAST THERMAL-OVERLOAD SWITCH. The OUT-FAST CONTACTOR closes, energizing the fast motor, which withdraws the rod at high speed.

The voltage across the coil of the OUT-FAST CONTACTOR is also applied through the normally-closed contacts of PLUGGING RELAY IN P, to the rectifier circuit which energizes RELAY OUT P. RELAYS IN P and OUT P are of the magnetic time-delay type which close rapidly when energized, but open only after a short time delay when de-energized. Energizing RELAY OUT P closes the normally-open contact across the IN-FAST PUSH BUTTON, but does not close the IN-FAST CONTACTOR because of the opened auxiliary contacts on the OUT-FAST CONTACTOR. When the OUT-FAST PUSH BUTTON is released, the OUT-FAST CONTACTOR opens the circuit to the fast motor and closes the auxiliary contact in the IN-FAST PUSH-BUTTON circuit. Because the IN-FAST PUSH BUTTON is shorted until plugging RELAY OUT P drops out, the IN-FAST CONTACTOR is energized, thus plugging the fast drive motor. The time delays on RELAYS IN P and OUT P are set to plug the fast motor approximately to standstill. The normally closed contacts of the plugging relays are used to prevent oscillation between plugging relays and motor contactors.

Operation when the IN-FAST PUSH BUTTON is depressed is similar to that described above.

When an emergency shutdown occurs, RELAY Y is de-energized, opening the OUT-SLOW and OUT-FAST PUSH-BUTTON circuits, and shorting the IN-SLOW and IN-FAST PUSH BUTTONS. If electric power is still available, both drive motors will then operate to insert the rod. When the rod has been fully inserted, the IN-LIMIT SWITCH removes excitation from the contactor coils, and the rod coasts to a stop. Plugging of the fast motor does not occur since RELAY Y is de-energized.

Running the rod beyond its normal limit of travel in either direction opens a limit switch which opens the contactor control circuit to prevent further motion in that direction. The thermal-overload contacts prevent operation of the overloaded motor until the contacts are reset, but do not affect operation of the other motor.

7. Regulating-Rod System--Rod No. 9--Component Description

Rod, rack, rack-bearing supports, and drive pinion for Rod No. 9 are identical with those for the emergency rods. The overtravel stop is also the same, although no limit-stop pinion is mounted on it. No provision is made to move the rod by means of a hand crank because it is impossible to drive backwards through the worm speed reducers.

7a. Regulating-Rod Drive

The regulating-rod drive is shown in Figure 2.19 with its drive pinion and overtravel stop. This unit consists of a slip-clutch, change gears, a differential drive, high and low-speed worm-gear reducers, and two drive motors, all mounted on a welded base.

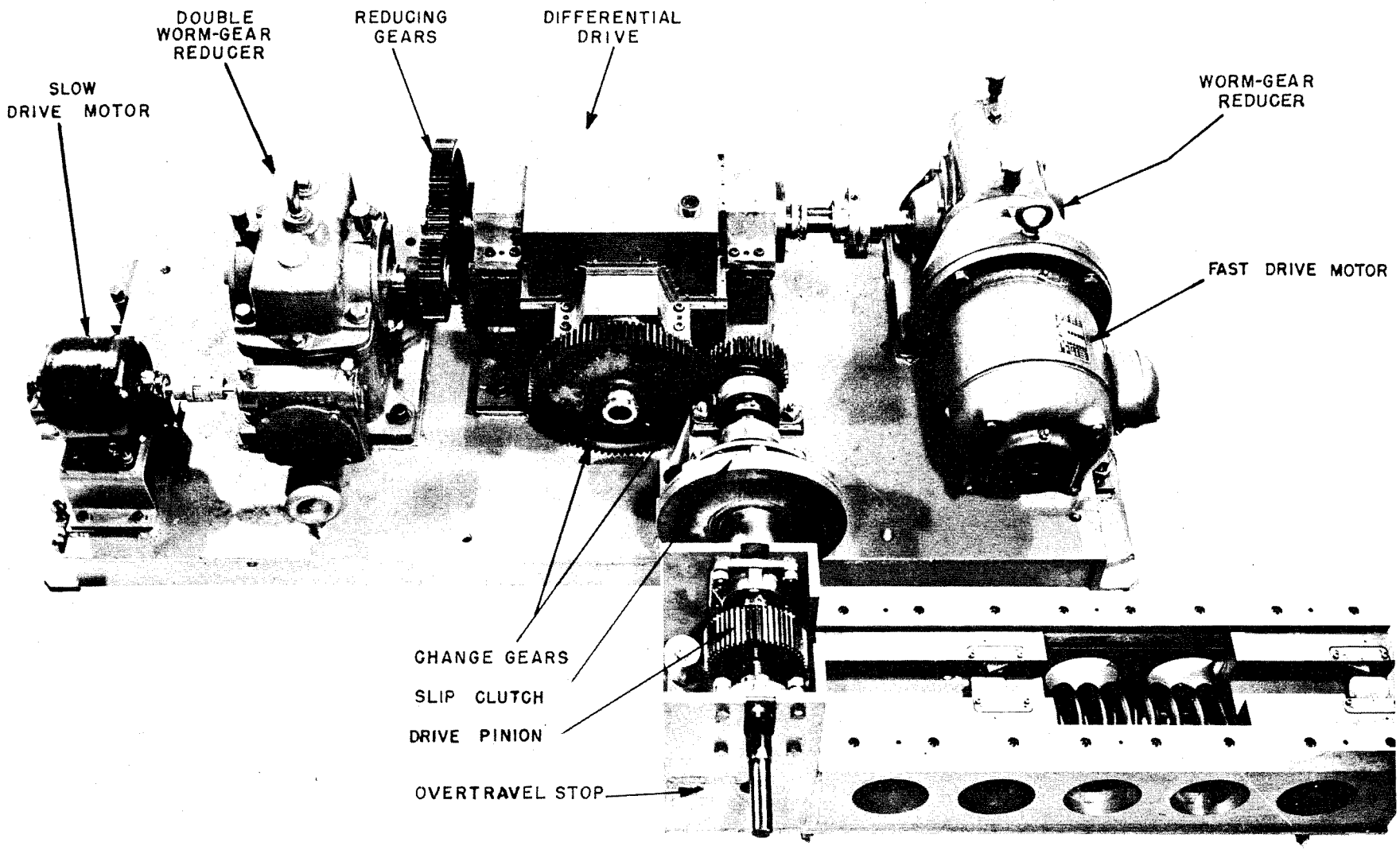


FIGURE 2.19 REGULATING-ROD DRIVE

The slip-clutch is a Bulletin No. 164, size eight coupling of the spring-loaded type, manufactured by the Hilliard Corp. It limits the torque output of the drive unit, thus protecting the driving mechanism as well as the rod and rack. The clutch is set to slip at a torque of 1800 inch-pounds. This torque is well below that required to compress fully the springs in the overtravel stop.

The change gears are eight-diametral-pitch gears with 1-1/2 inch face width. Tooth form is a full-depth involute with a twenty-degree pressure angle. All gears are hardened to increase resistance to surface wear. Possible gear ratios and the corresponding rod speeds are given in the table on page 2.41.

The differential drive is shown in Figure 2.20. It is an orthodox bevel-gear differential having a two-to-one speed reduction between either input shaft and the output shaft. The gear assembly is enclosed in a housing weldment and is splash lubricated by oil in the housing. A sight gauge is provided for observing the oil level. All gears are eight-pitch, 14.5-degree mitre gears.

The fast drive motor is part of a Size 35W unit supplied by the D. O. James Company. Besides the one horsepower, 440-volt induction motor, the unit includes a 43:1, high-speed worm-gear reducer. Full-load output speed of the unit is 40.2 rpm. A flexible coupling links the output shaft of the speed reducer to the high-speed input shaft of the differential.

The slow drive motor is a standard, type 5K43AC318A General Electric, 1/6-horsepower, 440-volt induction motor. It is coupled to

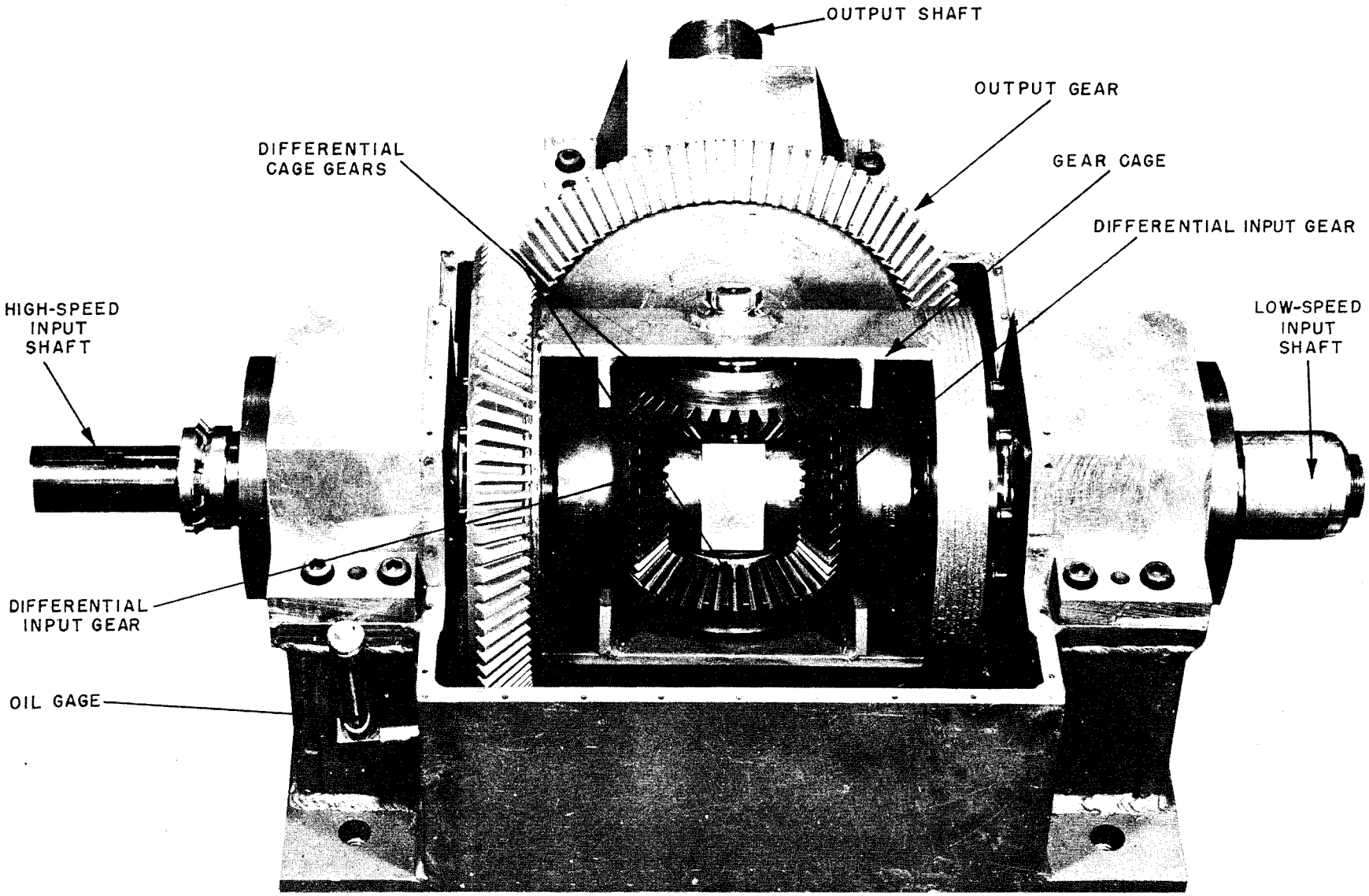


FIGURE 2.20 REGULATING-ROD DRIVE DIFFERENTIAL

its worm-gear reducer by a flexible coupling. The low-speed worm-gear reducer has a speed reduction of 1900:1. It is a double-worm unit, Size No. 274W, manufactured by D. O. James Company. When driven by the 1750 rpm slow-speed drive motor, the output speed of the reducer is 0.921 rpm.

A pair of spur-type reducing gears driven by the worm-gear reducer drops the input to the differential to 0.4605 rpm. They have a face width of 1 1/4 inches and are cut with eight-diametral-pitch, 20-degree pressure angle, involute teeth.

7b. Control Equipment

The air circuit breakers are of 100A frame-size with 15-ampere trip units. The reversing magnetic contactors are size one units with two auxiliary normally-closed contacts on each contactor. The fast-motor contactor is equipped with 1.66-1.82-ampere thermal overload relays, and the slow-motor contactor, with 0.40-0.44-ampere thermal overload relays.

The plugging relays, with their associated rectifiers and filters are mounted on the side of motor control center, P19. The relays are Type A39299 units manufactured by C. P. Clare and Co. Full-wave selenium rectifier stacks (Vickers No. B6BHNIEM) supply direct current for the plugging relays.

The limit switches are mounted on the rod structure and are actuated by the free end of the rack. These switches and their mountings are identical with those used to control the limit lights on the coarse rod-position indicator. For additional information on these switches, see Chapter III.

8. Regulating-Rod System--Rod No. 15--General Description

Regulating Rod No. 15 can be inserted and withdrawn in response to signals from the operator at the console. The operator can also use Rod No. 15 to control reactor power automatically. Because the automatic power regulator is faster than the combination of galvanometer and operator, it should control power more accurately than could a human operator. The automatic power regulator is also useful in reducing the magnitude of the power overshoot which occurs when the reactor is being brought up to full power. When an emergency shutdown occurs, Rod No. 15 is inserted at high speed.

The system used to control Rod No. 15 is shown schematically in Figure 2.21. The rod, rack, and driving mechanism (not shown in the figure) are identical with those used on Control Rod 9. The system for controlling the electric motors, including the plugging relays, is similar to that for Rod No. 9. The only difference is that switches in the power-level controller may take the place of the push buttons in actuating the motor starters. The source of control depends upon the position of the automatic-manual transfer switch.

In manual control, signals to the electric motors originate at the push buttons on the left-hand side of the console skirt, and pass to the motor starters at the control center through the automatic-manual transfer switch on the left wing of the console. In automatic control, three sources supply signals to the regulator. These are the ionization chamber in the reactor, the potentiometer in the rod-position transmitter for Rod No. 15, and the power-set knob on the left wing of the console.

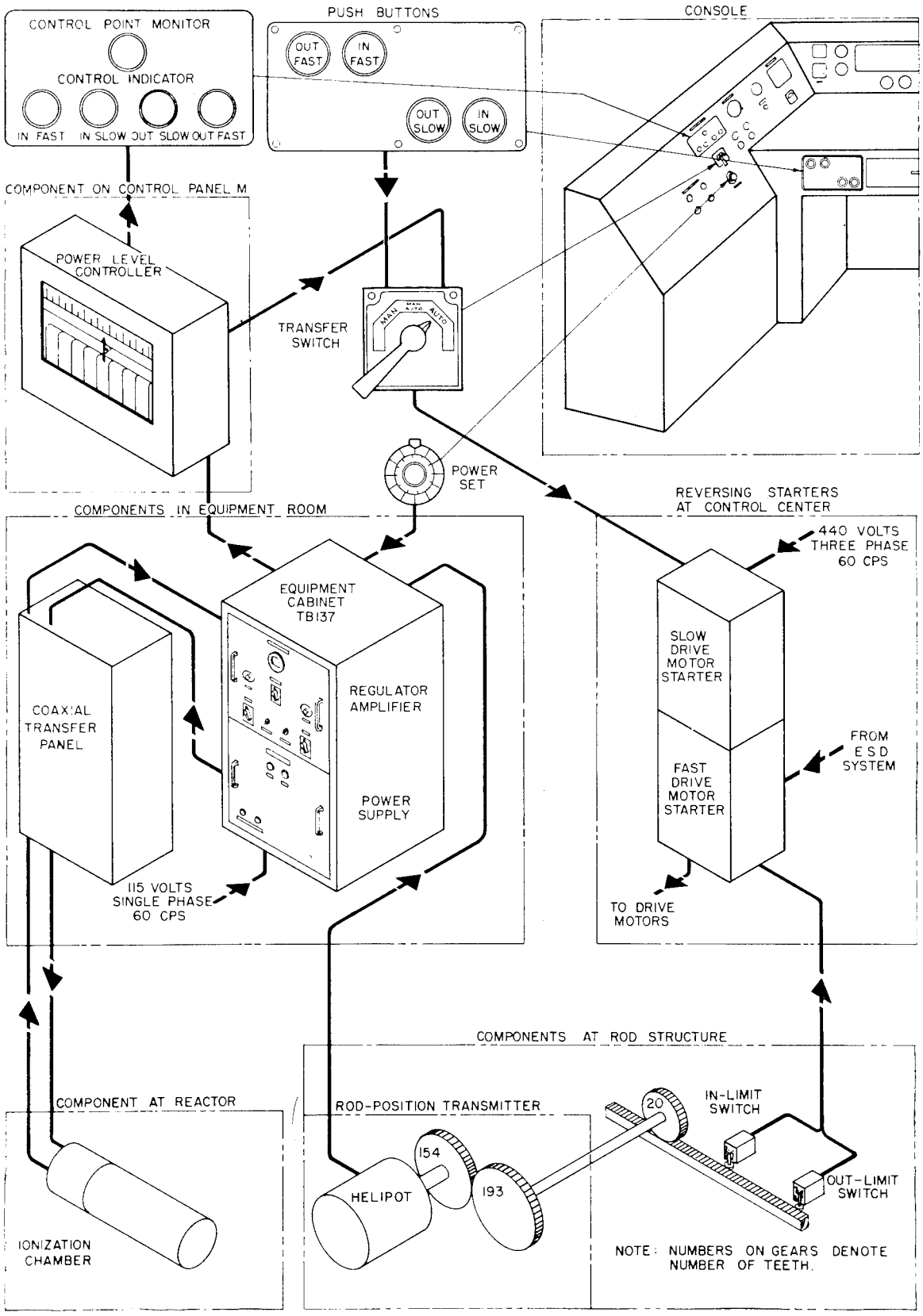


FIGURE 2.21 REGULATING-ROD SYSTEM - ROD NO 15

These signals are mixed and amplified in the regulator amplifier and a resultant signal is sent to the power-level controller on Control Panel M. The power-level controller, actuated by this input signal, closes contacts to produce signals that pass through the transfer switch to the motor starters. As a result, Rod No. 15 is driven in such a direction that the reactor power level is made approximately equal to that determined by the power-set knob. An auxiliary set of contacts in the controller illuminates the indicator lamps on the left wing of the console. These lamps show whether the rod should be inserted, or withdrawn, at high or low speed, or should remain stationary.

Specifications for output torque and possible rod speeds are identical with those for Rod No. 9. However, for automatic regulation of power level to be sufficiently fast to offset start-up transients, the 84-tooth and 36-tooth change gears are interchanged. This arrangement causes the drive pinion speed to be 2.33 times that of the output of the differential. High rod speed is then 12.3 inches per second (312 millimeters per second) and low rod speed is 0.141 inch per second (3.57 millimeters per second).

The automatic power regulator was designed to regulate reactor power to within plus or minus one-half of one per cent of full power. The effective range of automatic regulation is from ten per cent of full power to full power.

9. Regulating-Rod System--Rod No. 15--Operation

To operate Rod No. 15 manually, the transfer switch is rotated to MAN, and the push buttons on the left side of the console skirt are

used to drive the rod in fast, in slow, out fast, or out slow. When the transfer switch is in its MAN position, no power is supplied to the vacuum tubes in the regulator amplifier or to the power-level controller.

To operate the rod in its automatic mode, it is first necessary to rotate the transfer switch to the MAN-AUTO position and leave it there long enough for the vacuum tubes and the associated components in the regulator-amplifier and controller to establish thermal equilibrium. During this interval the indicator lights on the left wing of the console indicate the direction and speed of rod motion which would occur if automatic control were on. However, the rod is still controlled from the push buttons.

Rotating the transfer switch to its AUTO position puts the rod under control of the automatic regulator. The push buttons lose control, and the indicator lights show the direction and speed of rod motion. If insufficient time has been permitted for warmup, there will be some drift of reactor power for a given setting of the power-set knob. Similarly, if the electronic equipment is turned off and then turned on again, some drift may occur.

Figure 2.22 shows the circuits for control of the electric motors and the indicator lights. The motor control system is similar to that for Rod No. 9. The differences are that provision for switching from manual to automatic operation is made, and switches in the power-level controller are added. These switches substitute for the push buttons when the automatic regulator is operative. The action of plugging relays,

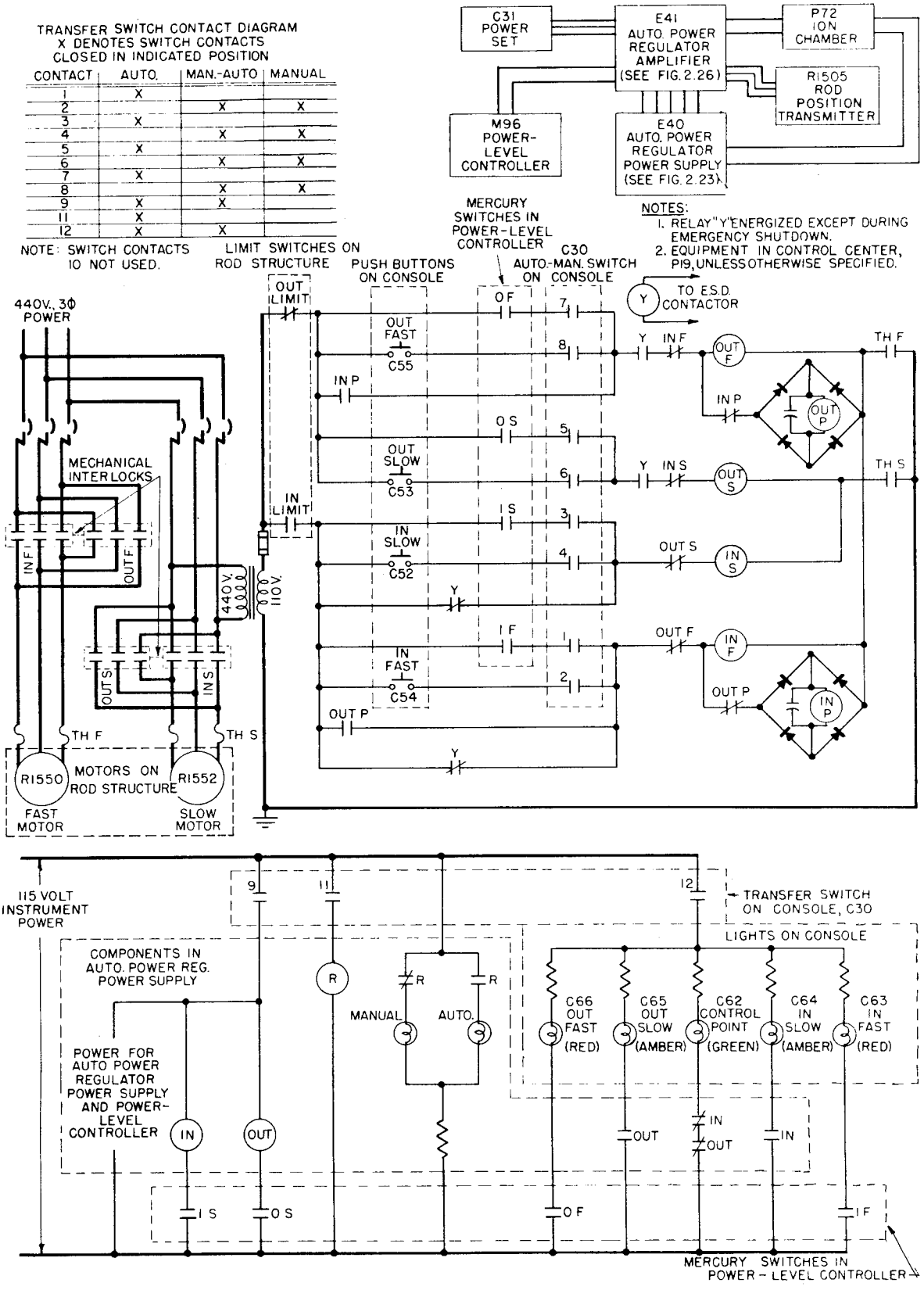


FIGURE 2.22 MOTOR-CONTROL AND INDICATING CIRCUITS FOR ROD NO. 15

thermal and limit switches, and emergency-shutdown relay for both modes of operation of Rod No. 15 is identical with the action of these devices for Rod No. 9. Motor starters and plugging and emergency-shutdown relays are located in motor control center P19.

In manual operation, contacts 2, 4, 6, and 8 of the transfer switch are closed, and contacts 1, 3, 5, and 7 are open. (See Figure 2.22.) Under this condition, operation of the motor control system is identical with that for Rod No. 9. In automatic operation, contacts 2, 4, 6, and 8 of the transfer switch are open and contacts 1, 3, 5, and 7 are closed. This arrangement switches control of the motor from the push buttons to four mercury switches in the power-level controller.

The switches are so arranged that the slow motor switch is closed whenever the fast motor switch is closed. Consequently, high-speed rod motion is produced by both motors driving the rod through the differential in the same direction.

The indicating lights on the console are controlled by the indicating circuit shown in the lower half of Figure 2.22. The five indicating lights are controlled by a second set of four mercury switches in the power-level controller. When the transfer switch on the console is in its AUTO or MAN-AUTO position, contacts 9 and 12 are closed. When none of the mercury switches are closed, the control point indicating lamp will be energized through the normally closed contacts of relays IN and OUT. When either the out-slow or the in-slow mercury switch is closed, one of the auxiliary relays, OUT or IN, in the

power supply is energized, turning on either the out-slow or the in-slow indicating lamp, and turning off the control-point lamp. The out-fast and in-fast lamps are controlled directly by their mercury switches in the controller. Because the SLOW switches remain closed when the FAST switches close, either the IN or OUT relay will be energized when one of the FAST switches is closed. Consequently, one of the SLOW lights will be on and the control-point light will be off when the rod is being driven at high speed.

Relay R in the power supply controls the manual and automatic indicating lamps on the power supply chassis. Contact 11 of the transfer switch is closed and relay R is energized only when the switch is in its AUTO position. Hence, when the transfer switch is on AUTO, the AUTO lamp is lighted, and when the transfer switch is on MAN or MAN-AUTO, the MANUAL lamp is lighted.

10. Regulating-Rod System--Rod No. 9--Component Description

Rod, rack, rack bearing supports, and overtravel stop of Rod No. 15 are the same as those for the emergency rods. The regulating-rod drive assembly for Rod No. 15 is identical to that for Rod No. 9, except for the change gears.

The transfer switch, C30, is manufactured by the General Electric Company (Type SB-1). It is a six-bank, three-position, lock-type switch. The condition of the contacts for each of the three switch positions is shown in Figure 2.22.

The push buttons are marked IN SLOW, C52, OUT SLOW, C53, IN FAST, C54, and OUT FAST, C55. These switches are all Cutler-Hammer Catalogue No. 10250H2757A switches, which make contact when depressed.

The power set knob, C31, on the console controls a type 150,000 EX potentiometer manufactured by The Helipot Corporation. This potentiometer is used to set the power level to which the reactor is to be automatically regulated. The dial is calibrated in megawatts.

The indicator lights located above the transfer switch on the console indicate to the operator the direction and speed of rod motion when automatic regulation is being used. Illumination of the green, CONT. PT, C62, lamp indicates that the reactor is operating at the desired level and neither drive motor is running. Illumination of IN FAST, C63, IN SLOW, C64, OUT SLOW, C65, or OUT FAST, C66, lamp indicates that the rod is travelling in fast, in slow, out slow, or out fast, respectively. When the rod is moving at fast speed in either direction, both lamps for that direction will be on.

The power-level controller, M96, is a Brown Instrument Co. type 153X12V-(III)-(IV)A, zero-centered, plus or minus five millivolt recorder, equipped with four pairs of mercury switches. These switches are adjustable in pairs throughout the full range of the instrument. One switch of each pair actuates one of the motors on the rod drive, and the other switch of each pair actuates the indicator lights on the console. The switches are initially set so that the slow motor will be actuated at approximately ten per cent of full scale of the recorder, and the fast motor will be actuated at 95 per cent of full scale of the recorder. When the FAST switches close, the SLOW switches are already closed and remain closed.

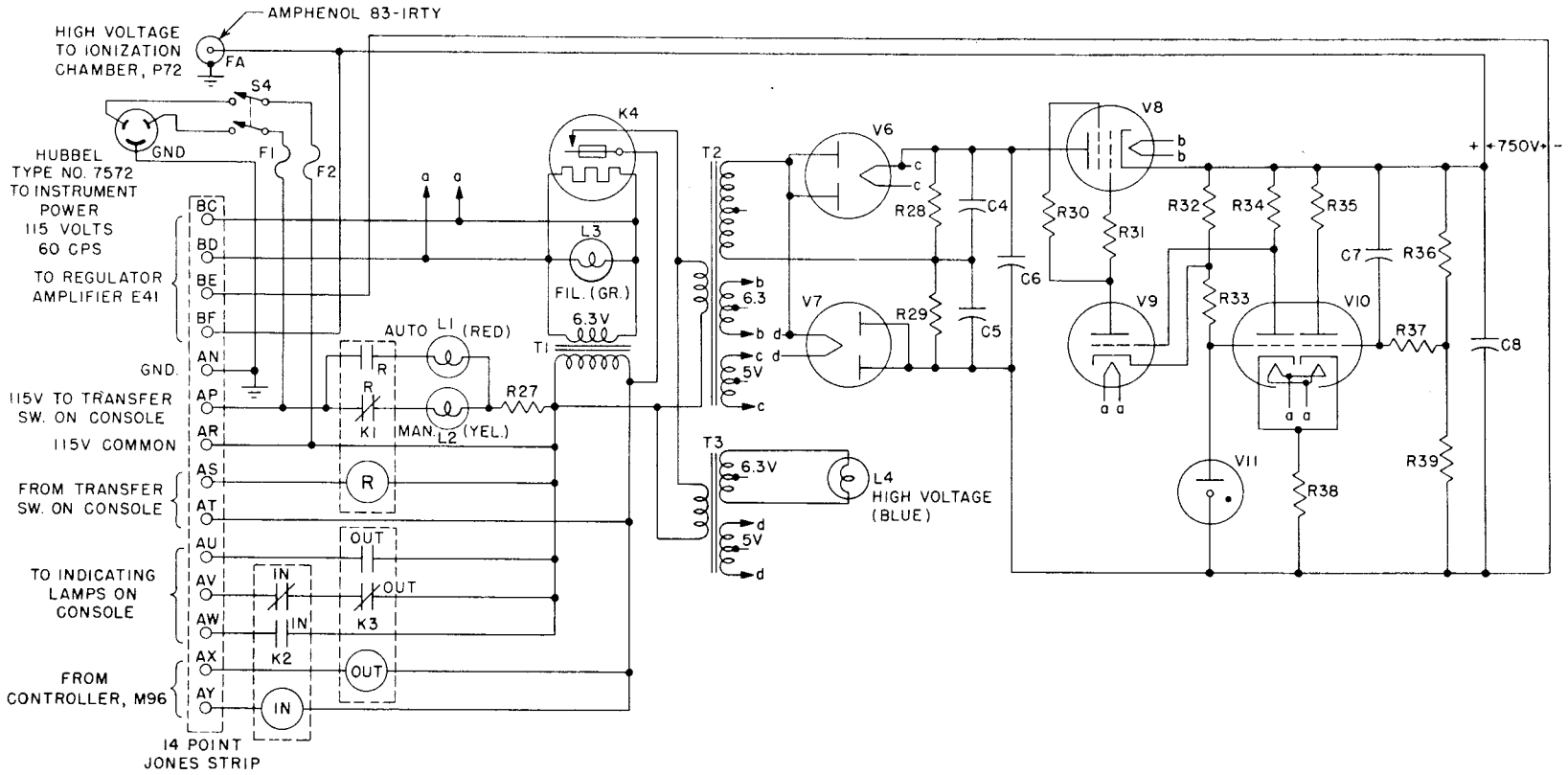
The helipot in the rod-position transmitter is a Model E potentiometer manufactured by The Helipot Corporation. Driven through a gear train by the rack, it sends rod-position signals to the regulator amplifier.

The ionization chamber is a three-inch chamber manufactured by the General Electric Company. It is designed to produce a signal of fifty microamperes, with 0.1 per cent background noise at full reactor power. The circuit in which this chamber is used is sufficiently flexible to function properly if the ionization-chamber current for full reactor power lies between thirty and fifty microamperes.

The regulated power supply for the automatic power regulator is shown schematically in Figure 2.23 and pictorially in Figures 2.24 and 2.25. This power supply is located in cabinet TB137 in the equipment room. It furnishes high-voltage for the ionization chamber and supplies plate power to the vacuum tubes in the regulator amplifier. It is rated at twenty milliamperes and 750 volts.

Power is received at 115 volts from the instrument power supply through the transfer switch on the console. The rectifier circuit is of the full-wave, voltage-doubler type. A regulator maintains the output at 750 volts under varying load and input conditions.

Auxiliary equipment in the power supply consists of thermal time-delay relay K4, magnetic relays K1, K2, and K3, and the four pilot lights. Time-delay relay K4 prevents the application of plate voltage to the tubes of the regulator amplifier before the cathodes have become heated. The filament (green) and high-voltage (blue) pilot lights indicate when these voltages are on. The three relays are the IN relay, OUT relay, and relay R, discussed previously.



R27- RESISTOR, 750 OHMS, 25 WATTS.
R28, R29- RESISTOR, 1.3 MEGOHM, 2 WATTS.
R30- RESISTOR, 2.2 MEGOHMS, 1/2 WATT.
R31- RESISTOR, 1000 OHMS, 1 WATT.
R32, R33- RESISTOR, 180,000 OHMS, 2 WATTS.
R34- RESISTOR, 2 MEGOHMS, 1/2 WATT.
R35, R37- RESISTOR, 100,000 OHMS, 1 WATT.
R36- RESISTOR, 1 MEGOHM ±1%, 1 WATT. I.R.C. WW2
R38- RESISTOR, 470,000 OHMS, 2 WATTS.
R39- RESISTOR, 125,000 OHMS ±1%, 1 WATT. I.R.C. WW4
C4, C5, C8- CAPACITOR, 10 MFD., 1000 VOLTS. OIL
C6- CAPACITOR, 6 MFD., 1500 VOLTS. OIL
C7- CAPACITOR, 4 MFD., 1000 VOLTS. OIL

V6, V7- VACUUM TUBE, TYPE 5V4G.
V8- VACUUM TUBE, TYPE 6AR6.
V9- VACUUM TUBE, TYPE 6SF5.
V10- VACUUM TUBE, TYPE 12AX7.
V11- VOLTAGE REGULATOR TUBE, TYPE 5651.
T1- TRANSFORMER, SOLA 30955.
T2- TRANSFORMER, STANCOR P6297.
T3- TRANSFORMER, KENYON T386.
K1, K2, K3- RELAY, D.P.D.T., ALLIED CONTROL CO. 806A110.
K4- RELAY, AMPERITE 6N060.
L1, L2, L3, L4- LAMP, TYPE 47. DIALCO
F1, F2- FUSE, 5 AMPERES, 250 VOLTS, BUSS 3AG.
S4- SWITCH, TOGGLE, D.P.S.T.

FIGURE 2.23 POWER SUPPLY FOR AUTOMATIC POWER REGULATOR

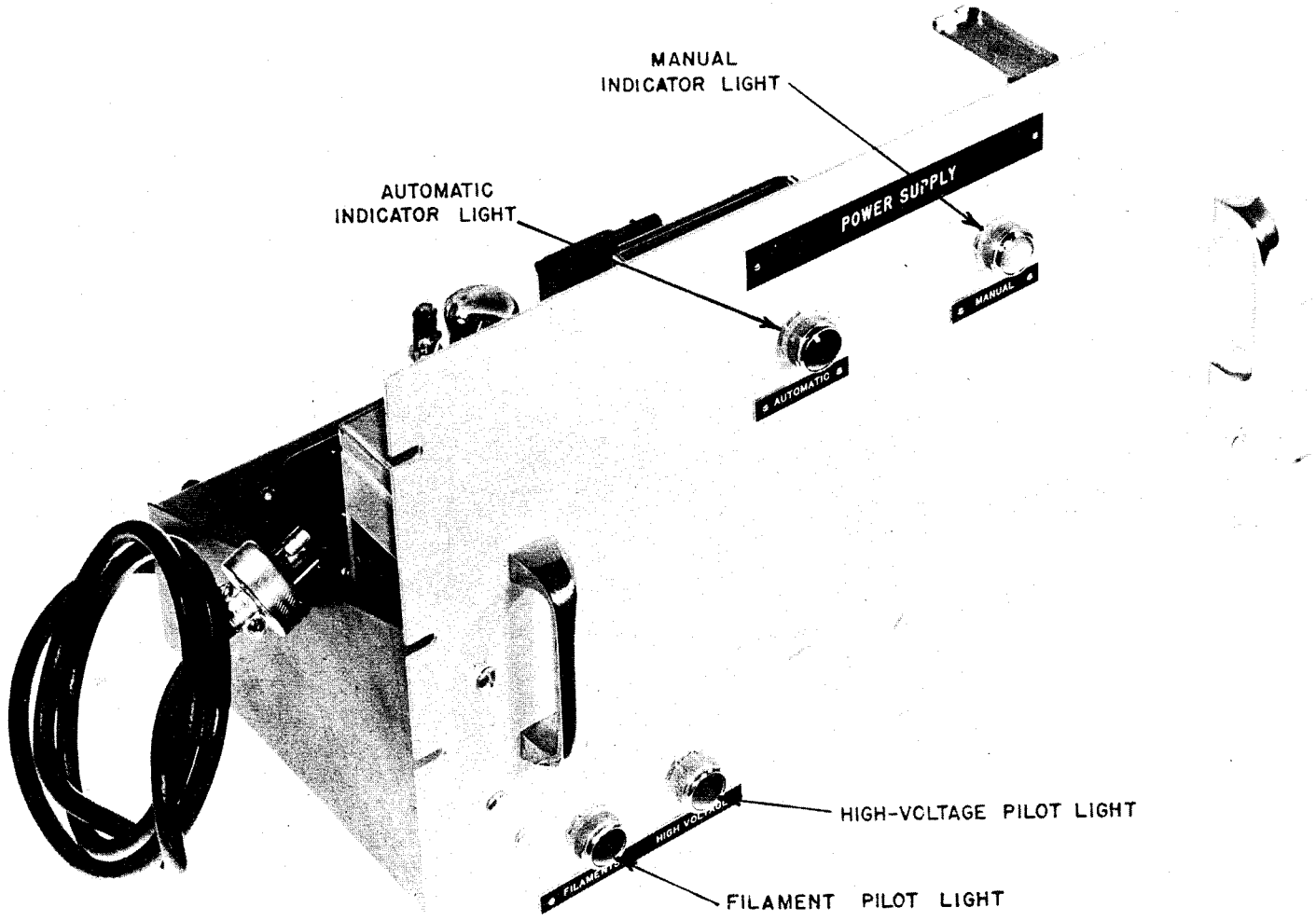


FIGURE 2.24 POWER SUPPLY FOR AUTOMATIC POWER REGULATOR

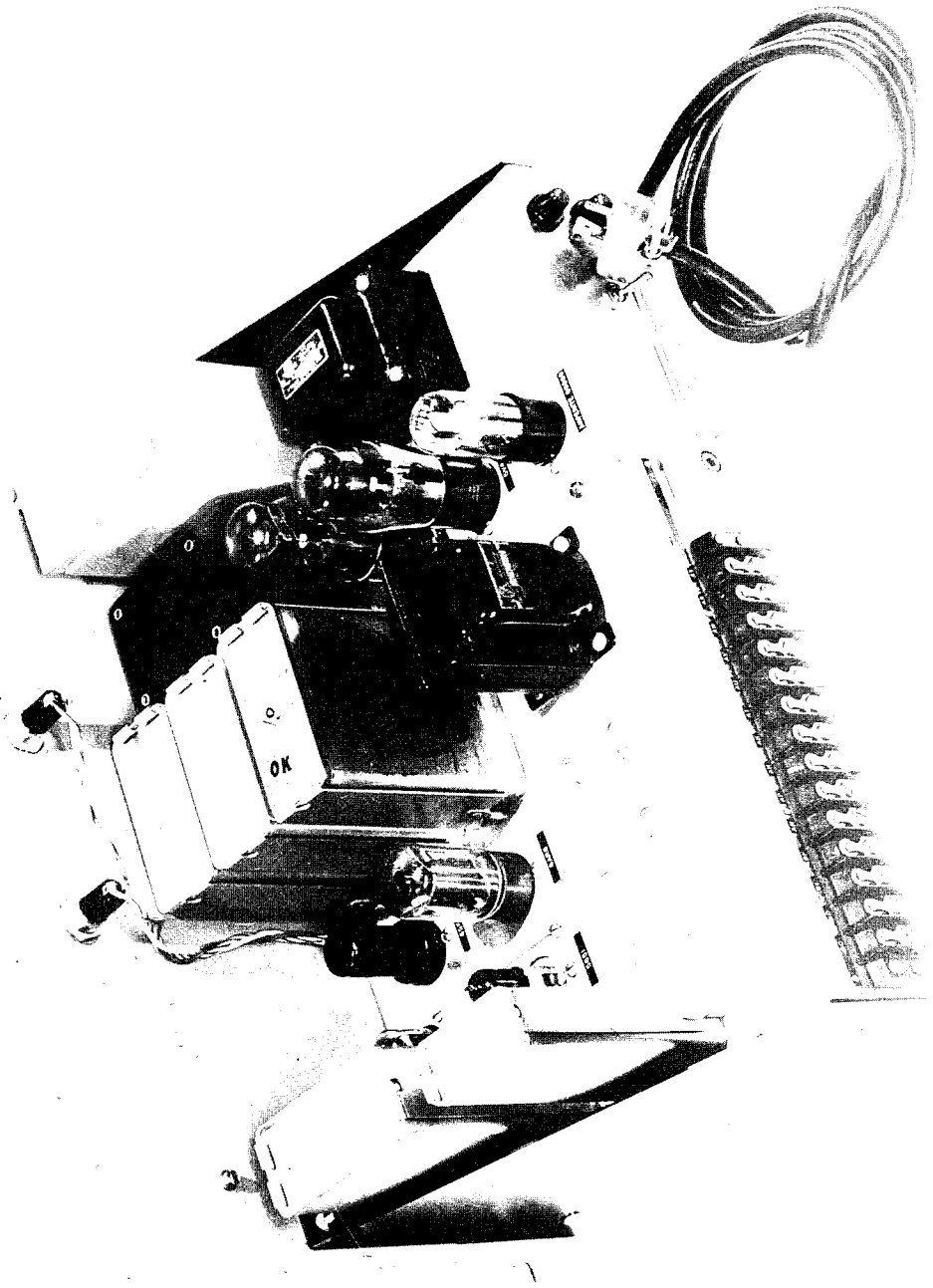
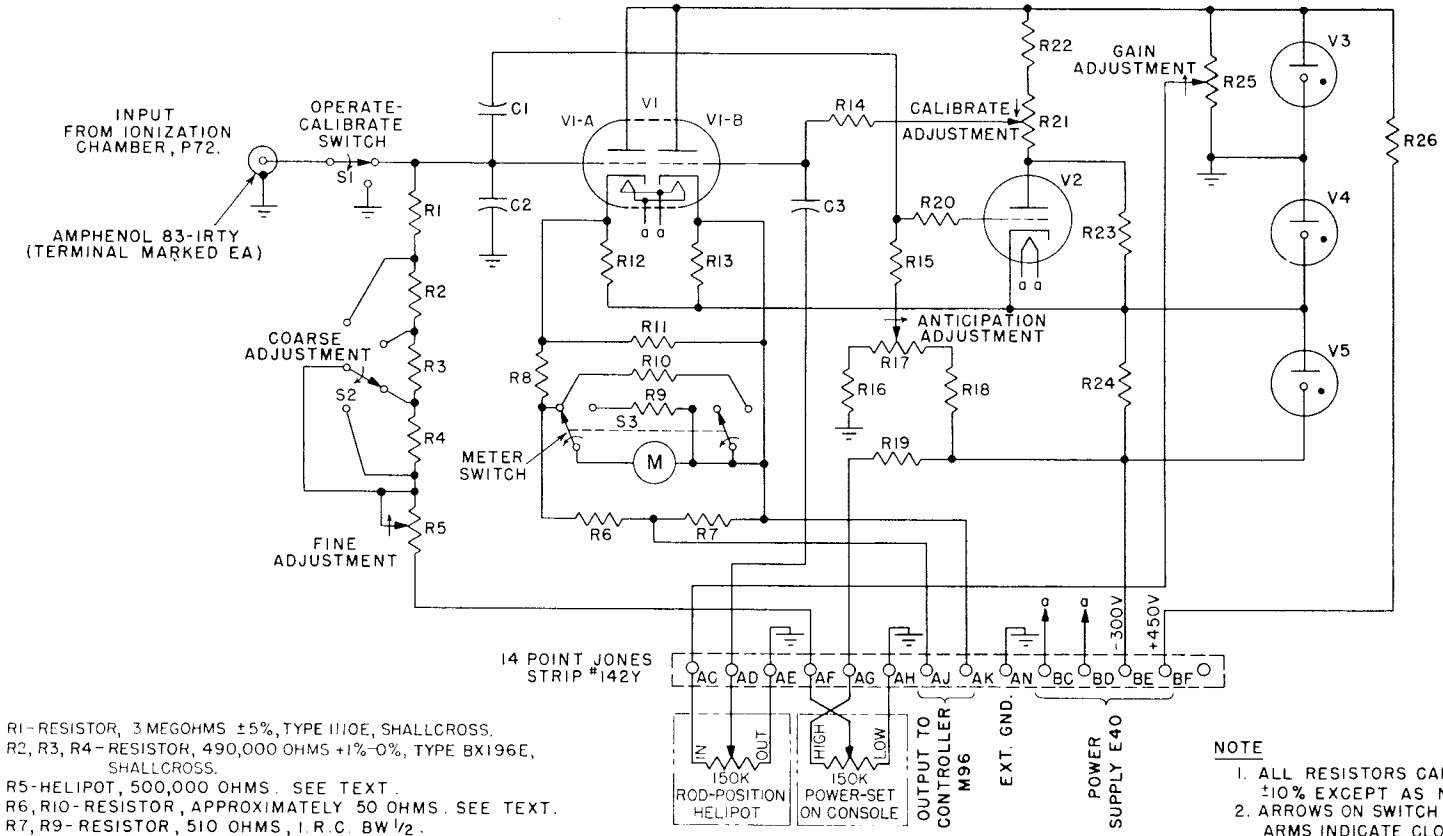


FIGURE 2.25 POWER SUPPLY FOR AUTOMATIC POWER REGULATOR

The regulator amplifier compares the current in the ionization chamber with that called for by the power-set potentiometer and sends a control signal to the automatic power level controller. In response to signals from the controller, Rod No. 15 is driven in or out to correct the power level and change the ionization-chamber current to the proper value. Auxiliary circuits modify and mix rod-position data from the helipot in the rod-position transmitter and the derivative of the error signal to improve the stability of the system.

The circuit of the amplifier is shown schematically in Figure 2.26. Figures 2.27 and 2.28 are photographs of the amplifier. A voltage proportional to the difference between the ion-chamber current and that called for by the power-set potentiometer is applied directly to the grid of triode V1-A. The two halves of twin triode V1 are connected as a dual cathode-follower, the output of which goes to the power-level controller. The grid of triode V1-B is driven by the signal from the rod-position potentiometer through condenser C3. The connections are such that inserting Rod No. 15 produces a signal at the input of the controller which would result in the rod being withdrawn. Hence, the resultant signal to the controller is the difference between the error signal and the rod-rate signal.

The other sections of the amplifier do not function during slow changes in reactor power or during very slow adjustment of the power-set potentiometer because triode V2 is biased beyond cut-off. The anticipation circuit is used only during rapid increases in reactor flux or rapid decreases in the setting of the power-set potentiometer.



R1-RESISTOR, 3 MEGOHMS ±5%, TYPE 111OE, SHALLCROSS.
R2, R3, R4-RESISTOR, 490,000 OHMS +1%-0%, TYPE BX196E, SHALLCROSS.
R5-HELIPOT, 500,000 OHMS. SEE TEXT.
R6, R10-RESISTOR, APPROXIMATELY 50 OHMS. SEE TEXT.
R7, R9-RESISTOR, 510 OHMS, I.R.C. BW 1/2.
R8-RESISTOR, 3900 OHMS, 1 WATT.
R11-RESISTOR, 1200 OHMS.
R12, R13-RESISTOR, 150,000 OHMS ±5%, MATCHED TO ±1%, TYPE BX116E SHALLCROSS.
R14-RESISTOR, 1.2 MEGOHMS ±5%, 1/4 WATT.
R15-RESISTOR, 10 MEGOHMS, 1 WATT.
R16, R18-RESISTOR, 1 MEGOHM, 1 WATT.
R17-POTENTIOMETER, 100,000 OHMS.
R19-RESISTOR, 63,750 OHMS, TYPE BX196E SHALLCROSS.
R20-RESISTOR, 100,000 OHMS, 1/4 WATT.
R21-POTENTIOMETER, 2000 OHMS, WIREWOUND.
R22, R23-RESISTOR, 50,000 OHMS, ±1% I.R.C. WW4

R24-RESISTOR, 43,000 OHMS, 2 WATTS.
R25-POTENTIOMETER, 250,000 OHMS, 2 WATTS.
R26-RESISTOR, 20,000 OHMS, 20 WATTS.
C1-CAPACITOR, 0.005 MFD. MICA.
C2-CAPACITOR, 0.3 MFD. DYKANOL.
C3-CAPACITOR, 0.5 MFD. DYKANOL.
V1-VACUUM TUBE, TYPE 5692.
V2-VACUUM TUBE, TYPE 6SF5.
V3, V4, V5-VOLTAGE REGULATOR TUBE, TYPE OD3/VR150.
S1, S3-SWITCH, ROTARY D.P.D.T., SHORTING TYPE, OAK CO.
S2-SWITCH, ROTARY, S.P. FOUR POSITION, CENTRALAB.
M-METER, 100-0-100 MICROAMP., SCALE 10-0-10, MARION, MODEL 53RN.

NOTE
1. ALL RESISTORS CARBON, TOLERANCE ±10% EXCEPT AS NOTED
2. ARROWS ON SWITCH AND POTENTIOMETER ARMS INDICATE CLOCKWISE ROTATION

FIGURE 2.26 REGULATOR AMPLIFIER

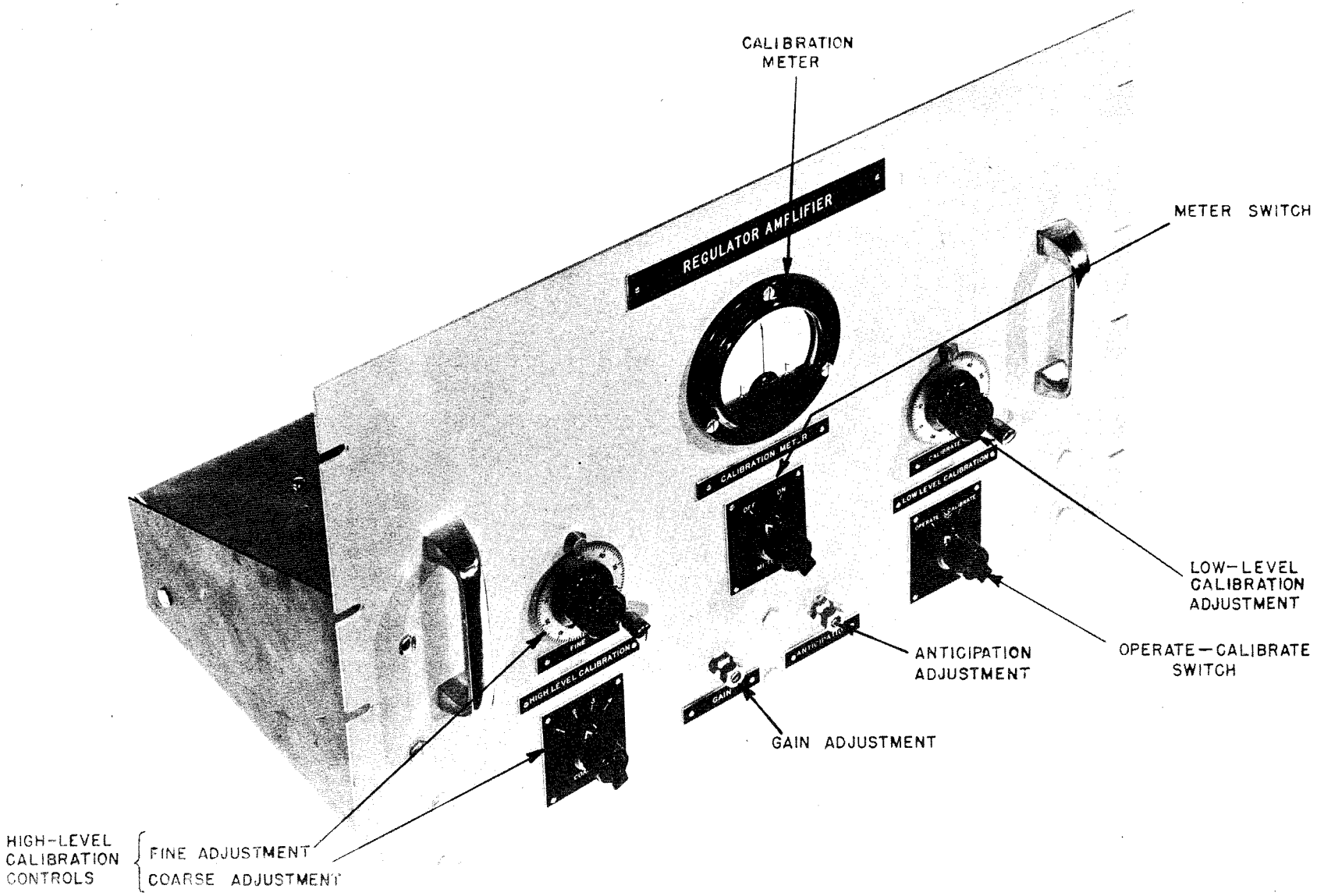


FIGURE 2.27 REGULATOR AMPLIFIER

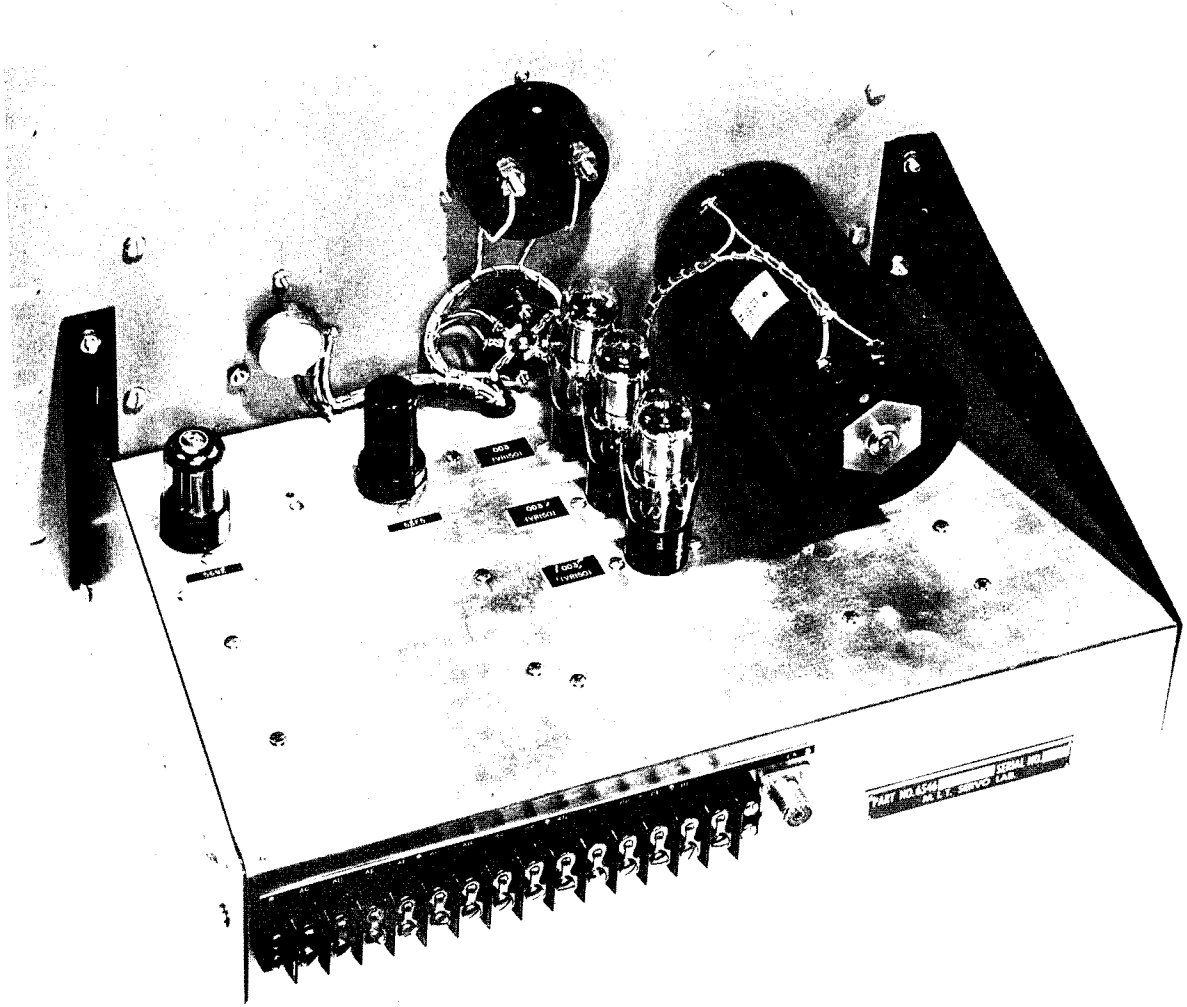


FIGURE 2.28 REGULATOR AMPLIFIER

When either of these events occurs, the grid of V2 is driven positive through condenser C1, causing the tube to conduct. The resulting plate signal is mixed with the rod-position feedback signal and applied to the grid of V1-B. The anticipation circuit is used primarily to stabilize the system by introducing the first derivative of the error signal when the automatic power regulator is being used to bring the reactor up to power.

The voltage-regulator tubes V3, V4, and V5 maintain the proper distribution of voltages among the circuit components. Filament power, as well as plate voltage, is supplied by the regulated power supply.

Several adjustments and one indicating device are available to balance, calibrate, and vary the gain of the amplifier. The meter used for calibrating and adjusting is a $\pm$100 microampere, zero-centered instrument which can be connected across the output of the dual cathode followers by means of the meter switch. The operate-calibrate switch disconnects the ionization chamber and grounds the amplifier input. The "calibrate" potentiometer, R21, is used to adjust the bias on triode V1-B. The amplifier output is balanced by adjusting the power-set potentiometer to zero power, placing the operate-calibrate switch on calibrate, turning the meter on, and adjusting the calibrate knob so that the meter reads zero.

The coarse and fine adjustments of the high-level calibration system short-circuit resistors R4, R3, and R2, and the potentiometer R5. The value of these resistors determines the ratio of voltage developed to ion-chamber current, and must be adjusted to match the particular ion

chamber used, so that the power-set calibration on the console will be correct.

Since the anticipation circuit is not to function except during large transients, V2 must be biased to cut-off by means of the screwdriver adjustment on potentiometer R17. The setting of the gain adjustment controls the gain of the rod-position feedback circuit. The optimum settings of these two adjustments can be determined only after considerable operating experience has been gained.

11. Parts List - Emergency-Rod System - Equipment at Rod Structure Drawing 6546RN006

Refer to Fig. 2.29	Name of Part	Part Number	No. Req.
	Rack and Rod Assembly	6546DN008	16
	Control Rod - H. K. Ferguson Co.	M-702-9C	1
	Rack - Front Section	6546CP010	1
1	Rack - Center Section	6546CP009	4
	Rack - Rear Section	6546CP008	1
3	Splice Plate	6546BP014	5
4	Stripper Bolt	6546AP067	25
2	Dowel Pin	6546AP149	15
	Socket Head Bolt	6546AP148	6
Fig. 2.30			
	Rack Bearing Support Assembly	6546EN001	144
1	Wedge Plate Weldment	6546EP002	1
2	Stud	6546AP042	4
3	Bolt	6546AP005	3
4	Bolt	6546AP006	4
5	Bolt	6546AP063	3
6	Top Wedge) Assembled in	6546CP004	1
7	Bottom Wedge) matched pairs	6546CP005	1
	Bearing Assembly	6546DN001	1
9	Base Casting	6546DP004	1
10	Bearing Cap	6546AP039	2
	Bottom Roller Assembly	6546BN009	1
11	Shield	6546AP008	2
12	Bottom Roller	6546BP017	1
13	Bearing, Fafnir or equal	M-204K	2
14	Shaft	6546BP018	1
8	Side Roller Assembly	6546BN008	2
15	Bearing, McGill or equal	MO-12-N	1
16	Side Roller	6546AP033	1
17	Retainer	6546AP038	1
18	Spacer	6546AP041	1
19	Shaft	6546BP019	1
Fig. 2.31			
	Overtravel Stop Assembly	6546EN022	14
1	Frame Weldment	6546EP010	1
2	Slideway	6546CP057	2
3	End Plate	6546CP045	1
	Buffer Assembly	6546CN009	1
4	Buffer Spring (Outer)	6546BP106	1
5	Buffer Spring (Inner)	6546BP107	1
6	Spring Block	6546CP042	1
7	Guide Tube	6546BP105	1
8	Guide Rod	6546BP104	1
9	Spring Block	6546CP039	1

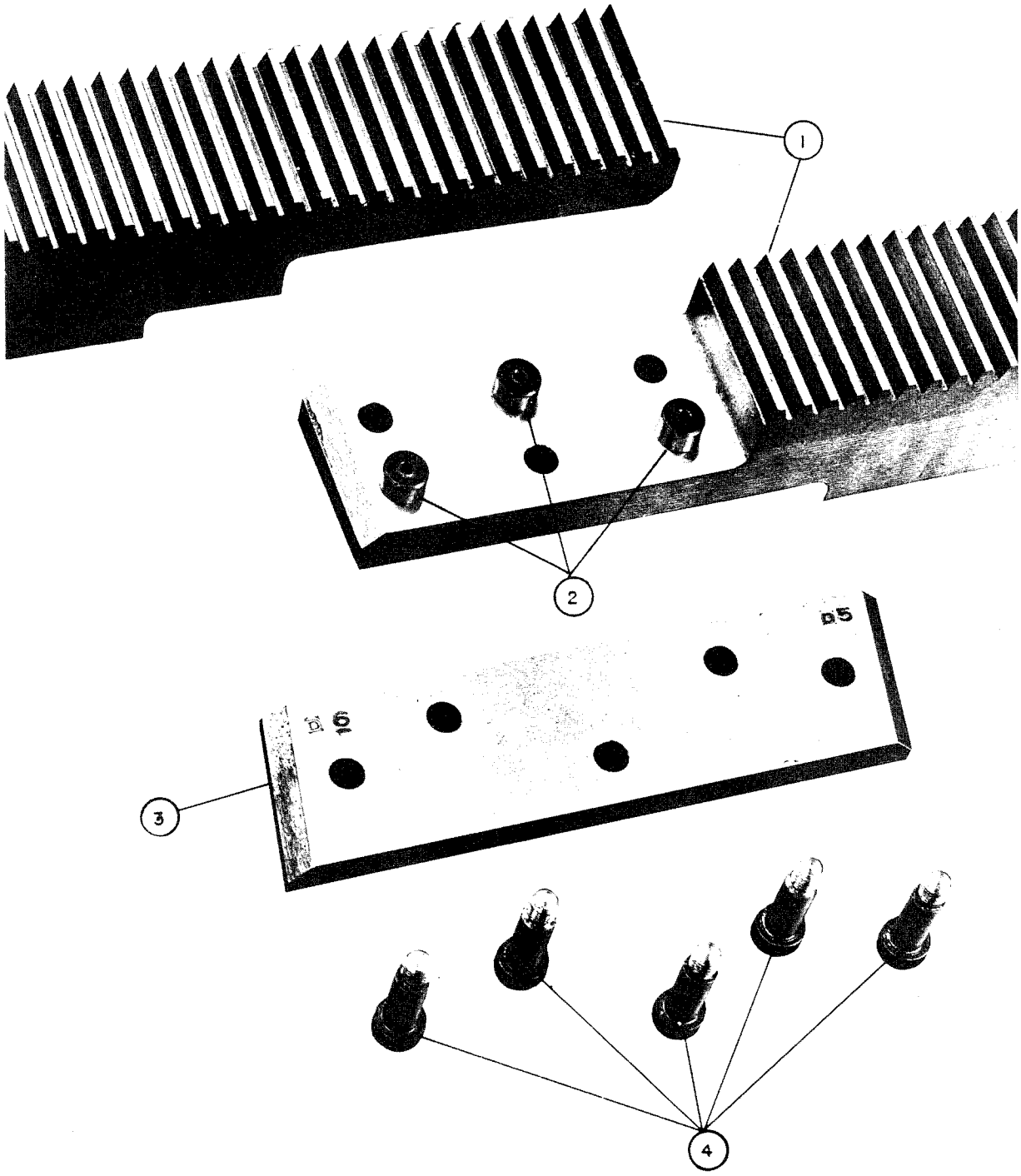
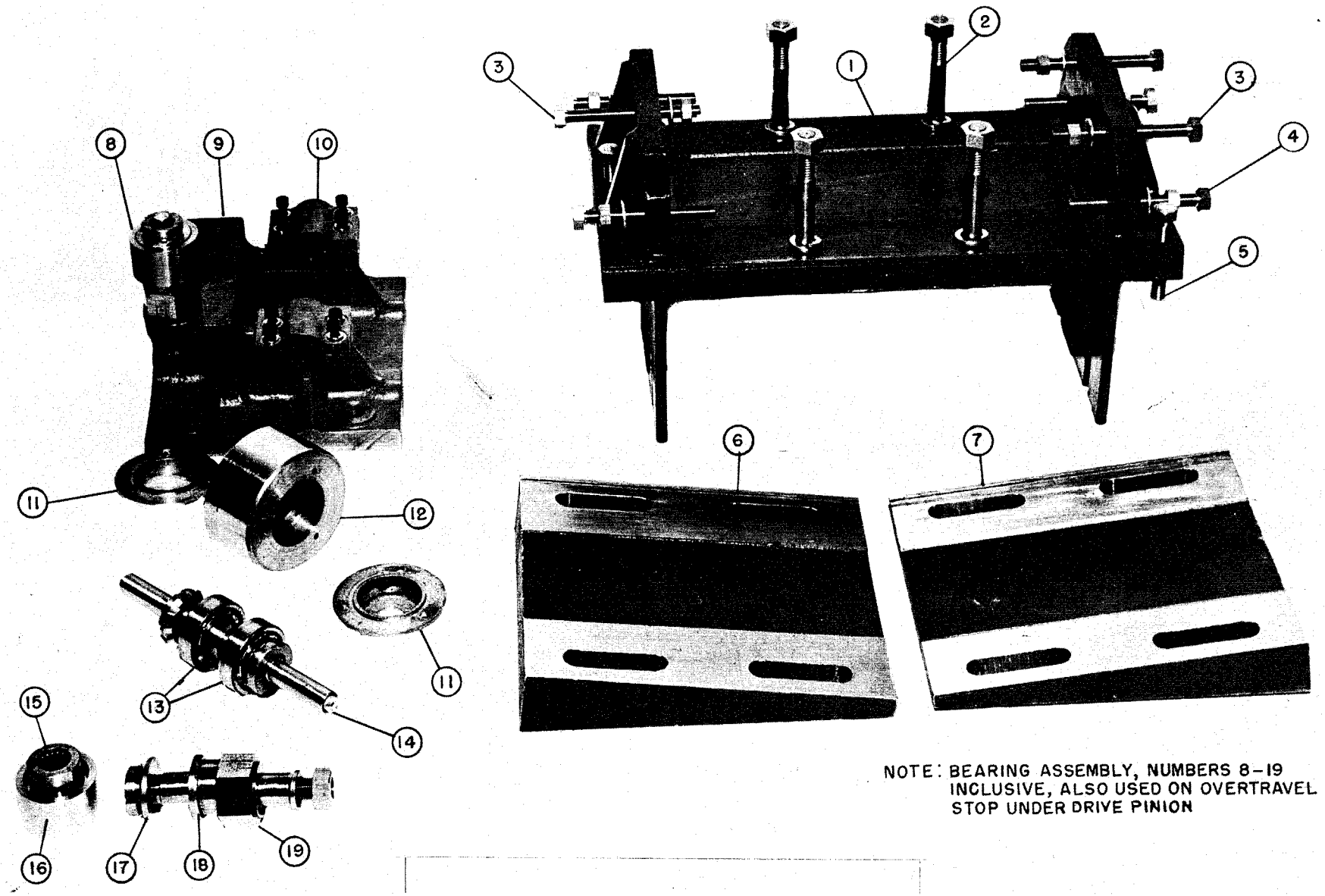


FIGURE 2.29 RACK-RACK SPLICE



NOTE: BEARING ASSEMBLY, NUMBERS 8-19 INCLUSIVE, ALSO USED ON OVERTRAVEL STOP UNDER DRIVE PINION

FIGURE 2.30 RACK BEARING SUPPORT

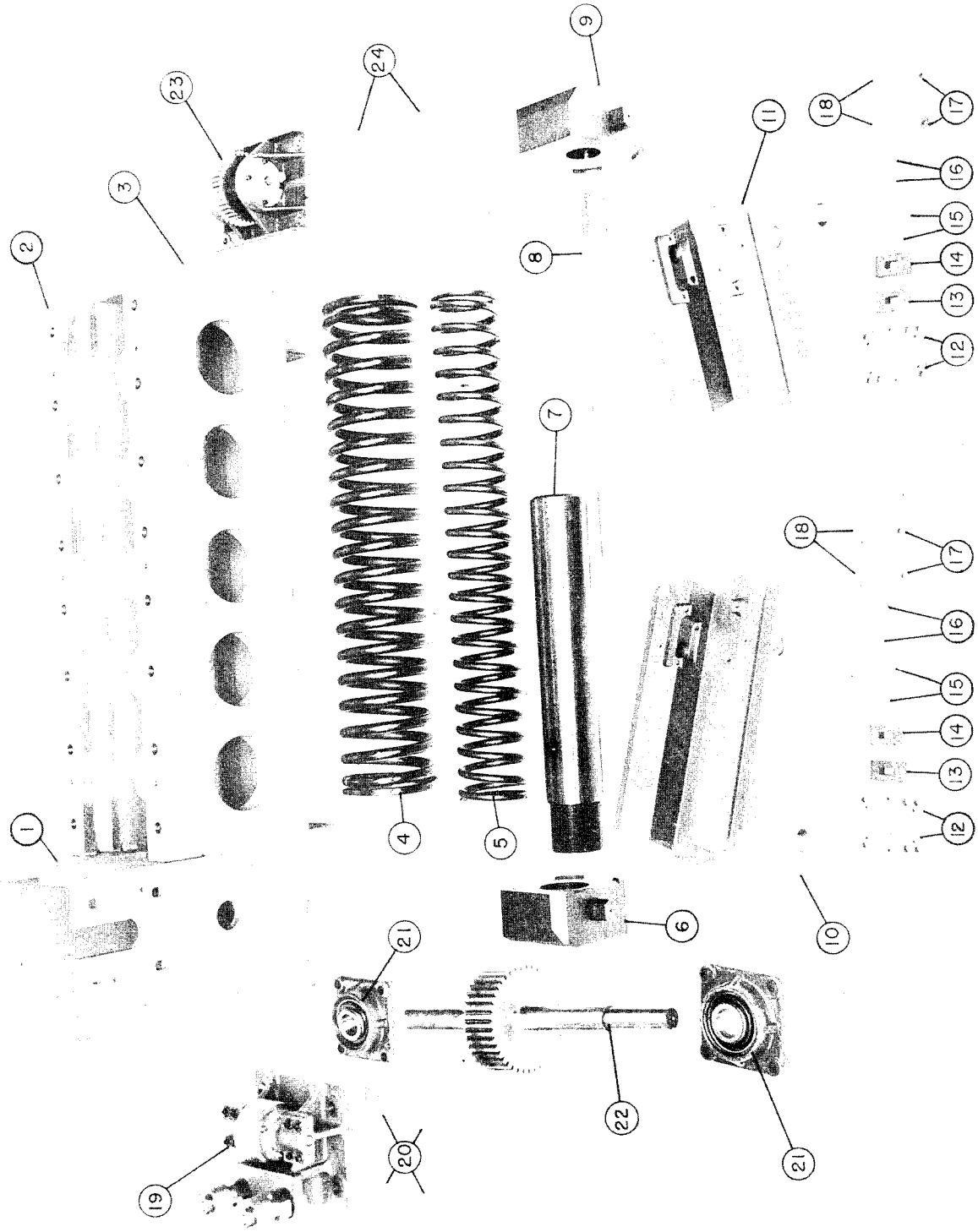


FIGURE 2.31 OVERTRAVEL STOP

Refer to Fig. 2.31	Name of Part	Part Number	No. Req.
	Stop Slide Assembly - Long	6546DN020	1
10	Stop Slide Weldment - Long	6546DP039	1
12	Pawl Plate	6546AP119	2
13	Stop Pawl - Left	6546AP140	1
14	Stop Pawl - Right	6546AP121	1
15	Pawl Spring - Outer	6546AP117	2
16	Pawl Spring - Inner	6546AP116	2
17	Pawl Roller	6546AP120	2
18	Spring Pin	6546AP118	2
	Stop Slide Assembly - Short	6546DN021	1
11	Stop Slide Weldment - Short (All other parts identical with those for Stop Slide Assembly - Long)	6546DP036	1
19	Bearing Assembly (For parts see Rack Bearing Support Assembly)	6546DN001	1
20	Shim	6546AP122	4
21	Cartridge Bearings, Fafnir or equal	LCJ 1 1/4	2
22	Drive Pinion	6546BP108	1
24	Shim	6546AP171	2
Fig. 2.32			
23	Limit Stop Pinion Assembly	6546DN019	1
1	Base Casting	6546DP035	1
2	Bearing Cap	6546AP111	1
3	Limit Stop Pinion	6546BP103	1
4	Bearing Cap	6546AP110	1
5	Shaft	6546BP087	1
6	Ball Bearing, Fafnir or equal	302K	1
Fig. 2.33			
	Hand Crank Assembly	6546DN002	14
	Lever Assembly	6546CN002	1
1	Bushing	6546AP009	2
2	Lever Weldment	6546DP010	1
3	Shoulder Pin	6546AP040	1
	Ratchet Assembly	6546BN007	1
20	Ratchet	6546BP016	1
21	Key	6546AP007	1
	Pawl Rod Assembly	6546CN001	1
4	Handle	6546BP022	1
5	Clevis Pin	6546AP034	1
6	Pin 1/16 x 1/2 long - Groov-Pin Corp.	Type 1	2
7	Rod End	6546AP048	1
8	Washer 1/4 x 11/16 x .051	Commercial	

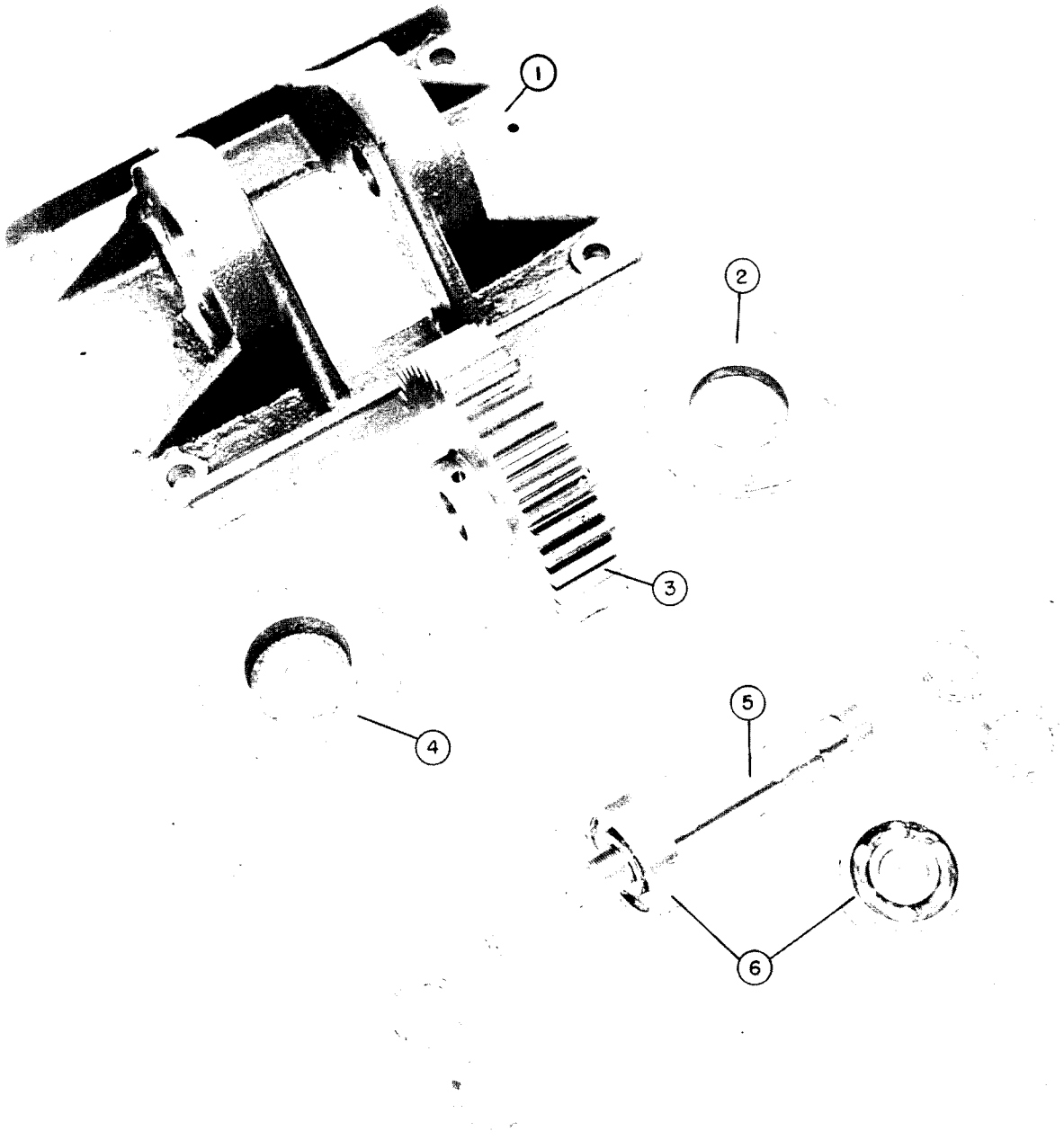


FIGURE 2.32 LIMIT-STOP PINION

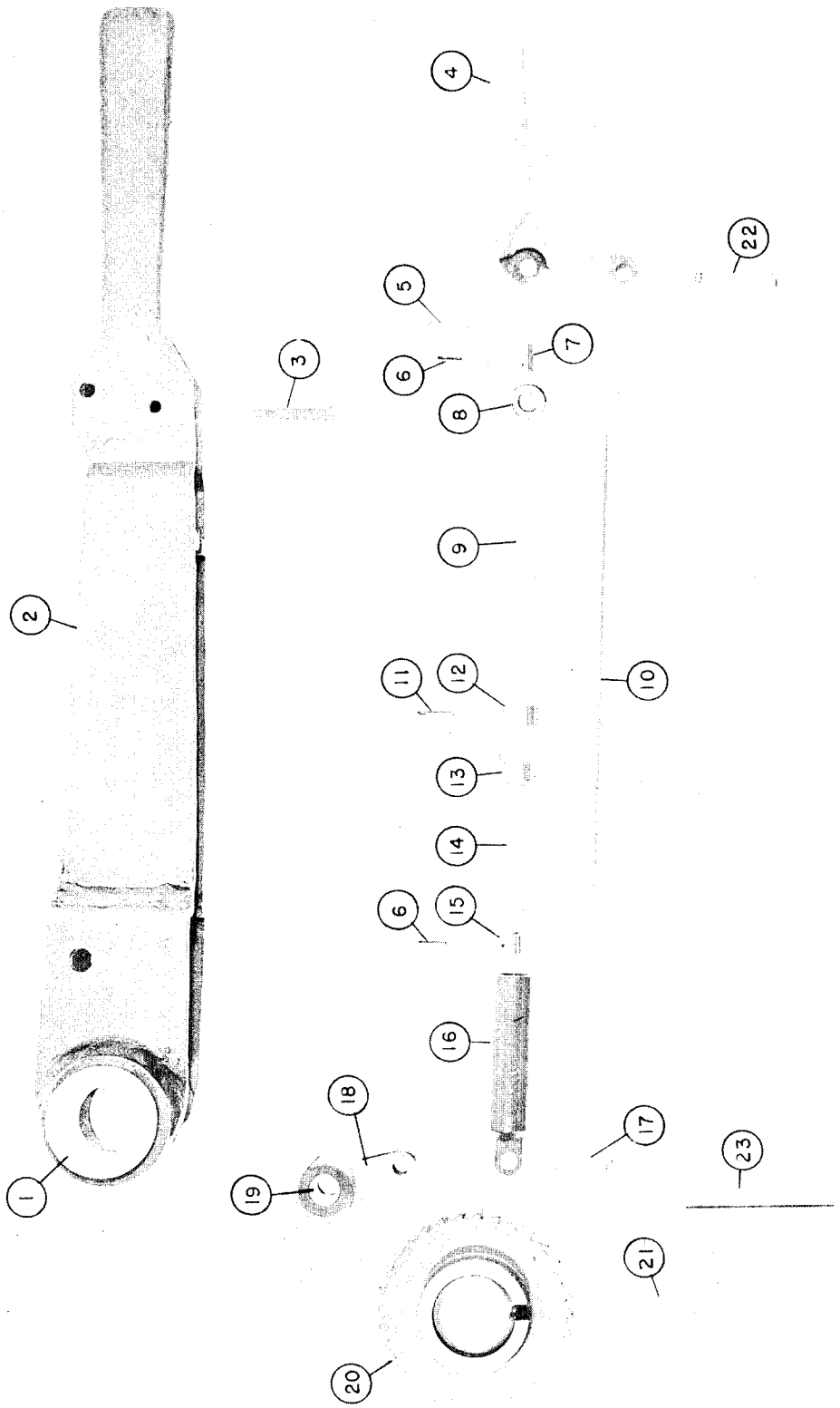


FIGURE 2.33 HAND CRANK - DISASSEMBLED

Refer to Fig. 2.33	Name of Part	Part Number	No. Req.
9	Spring	6546AP051	1
10	Spring Rod	6546AP047	1
11	Pin 1/16 x 5/8 long - Groov-Pin Corp.	Type 1	1
12	Collar	6546AP050	1
13	Rod Bearing	6546AP044	1
14	Spring	6546AP052	1
15	End Collar	6546AP049	1
16	Spring Housing Weldment	6546AP046	1
17	Pin	6546AP036	1
	Pawl Assembly	6546AN005	1
18	Pawl	6546BP021	
19	Bushing Oilite	A-531	1
22	Handle Bearing Pin	6546AP057	1
23	Bearing Pin	6546AP035	
	Emergency Drive Unit Assembly	6546DN005	14
	Support Weldment	6546DP012	1
	Hydraulic Motor Oilgear Co.	H-811	1
	Pipe Assembly	6546BN047	1
	Packing - "O" Ring E. F. Houghton Co. VIX-SYN	S-7-9	1
	Gear Coupling	6546BP030	1
	Gear Reducer - Philadelphia Gear Works R. H. Assembly 3.36:1	3103	1
	Shim	6546AP010	4
	Gear Coupling	6546BP031	1
	Emergency Pump Assembly	6546EN036	8
	Emergency Pump Weldment	6546RP005	1
	Gear Coupling	6546BP003	1
	Flywheel Guard Assembly	6546DN044	1
	Gear Coupling	6546BP032	1
	Pressure Gage - U.S. Gage No. 500 Std., 3 1/2 dial	0-160 Psi	1
	Firomatic Vent Cap - Morse-Smith-Morse, or equal	V-1S	1
	Pressure Switch Mounting Assembly	6546BN045	1
	Gage Glass	6546AP333	1
	Motor and Tachometer Assembly	6546DN030	1
	Tachometer Casting	6546DP053	1
	Shaft Extension and Coupling Assembly	6546AN039	1
	Flexible Coupling Insert - Certified	Size 1	1
	Flexible Coupling (Half) - Certified	Size 1	1
	Tachometer Assembly	6546CN029	1
	Tachometer, Reoperated	6546CP060	1
	Tachometer Ring	6546AP231	1
Fig. 2.34	Flywheel and Bearings	6546EN007	1
	Flywheel	6546DP013	1

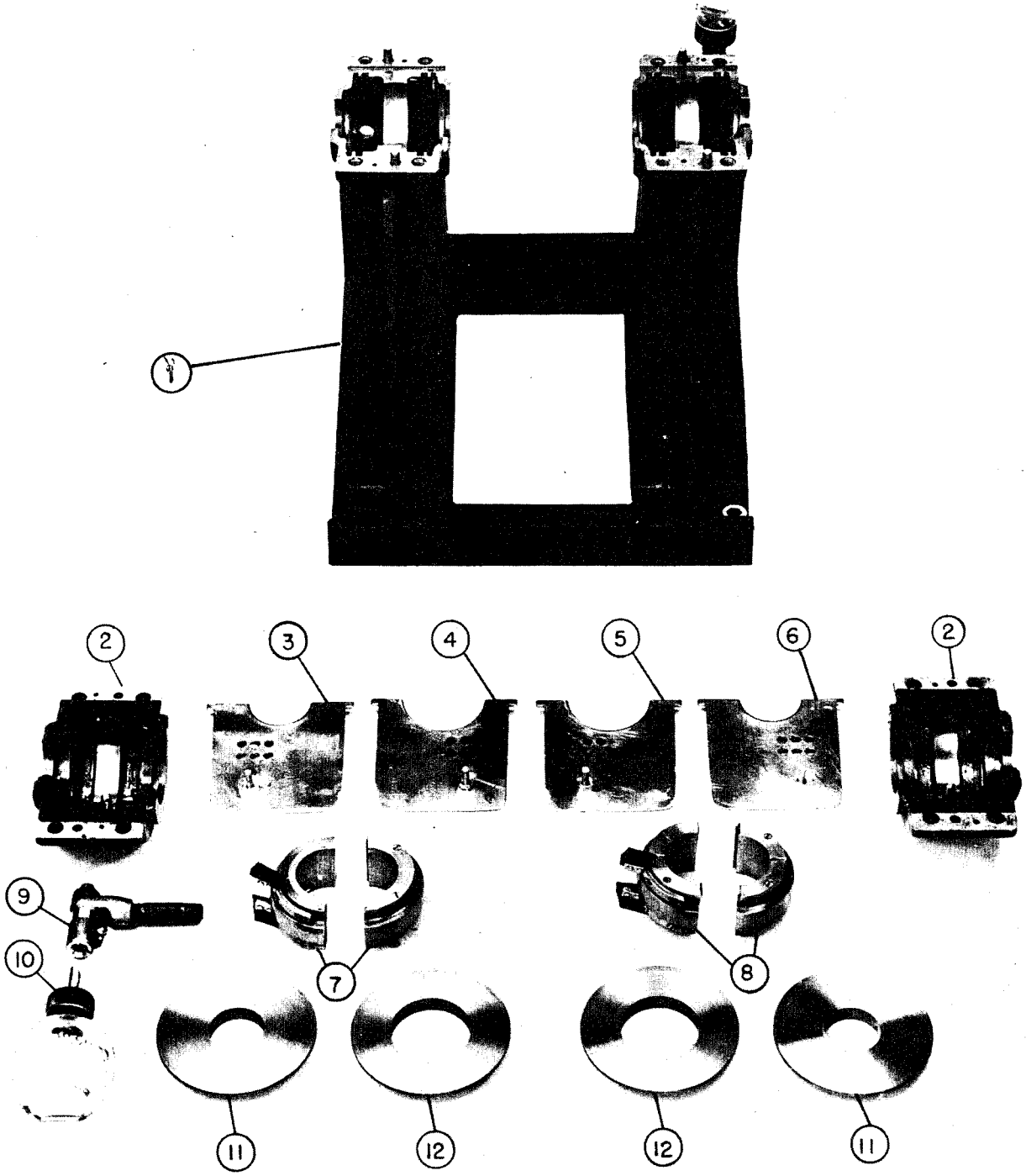


FIGURE 2.34 FLYWHEEL SUPPORT AND BEARINGS - DISASSEMBLED

Refer to Fig. 2.34	Name of Part	Part Number	No. Req.
12	Oil Disk - Inner	6546BP027	2
11	Oil Disk - Outer	6546BP026	2
9	Oil Container Support		2
10	Alvor Container - Flat Side Glass Lunkenheimer	301L	2
3	Baffle	6546BP413	
4	Baffle	6546BP416	1
5	Baffle	6546BP415	1
6	Baffle	6546BP414	1
7	Bearing and Wiper Assembly - Pump Side		
	Bearing Assembly	6546BN072	1
	Wiper Assembly	6546AN048	1
	Wiper Assembly	6546AN049	1
8	Bearing and Wiper Assembly - Motor Side		
	Bearing Assembly	6546BN010	1
	Wiper Assembly	6546AN048	1
	Wiper Assembly	6546AN049	1
	Base Assembly	6546DN009	1
1	Base	6546EP009	1
2	Cap and Gasket Assembly	6546AN045	1
	Emergency Rod Control Assembly	6546EN038	1
	Hydraulic Pump - The Oilgear Co. Drg.	56746	1
Fig. 2.35	Stroke Control Assembly	6546DN045	1
	Stroke Control and Pump Machining Assembly	6546DN050	1
	Stroke Control Machining Assembly	6546DN041	1
A	Piston and Valve Body	6546DP115	1
B	Torque Motor Plate	6546DP116	1
C	Bearing Support	6546CP125	1
1	Limit Stop Spool	6546AP422	1
2	Yoke	6546AP421	1
3	Plunger	6546AP422	1
4	Thimble	6546AP424	1
5	Emergency Shutdown Spring	6546AP649	1
6	Solenoid National Acme Co.	KKK100CP8A	1
7	Shim	6546AP427	1
8	Plate	6546AP426	1
9	Torque Motor - A.C. Control Motor Diehl	FPM49-10-2	1
10	Cylinder Cap	6546BP287	1
11	Shim	6546AP403	1
12	Power Piston	6546BP286	1
15	Restraining Spring Assembly	6546BN062	1
16	Spring - Hardware Products Co. .023 wire, .063 Pitch 3/16 OD x 2" lg.		
17	Pin - Power Piston	6546AP401	1
18	Feedback Lever	6546BP285	1
19	Dither Link	6546AP397	1

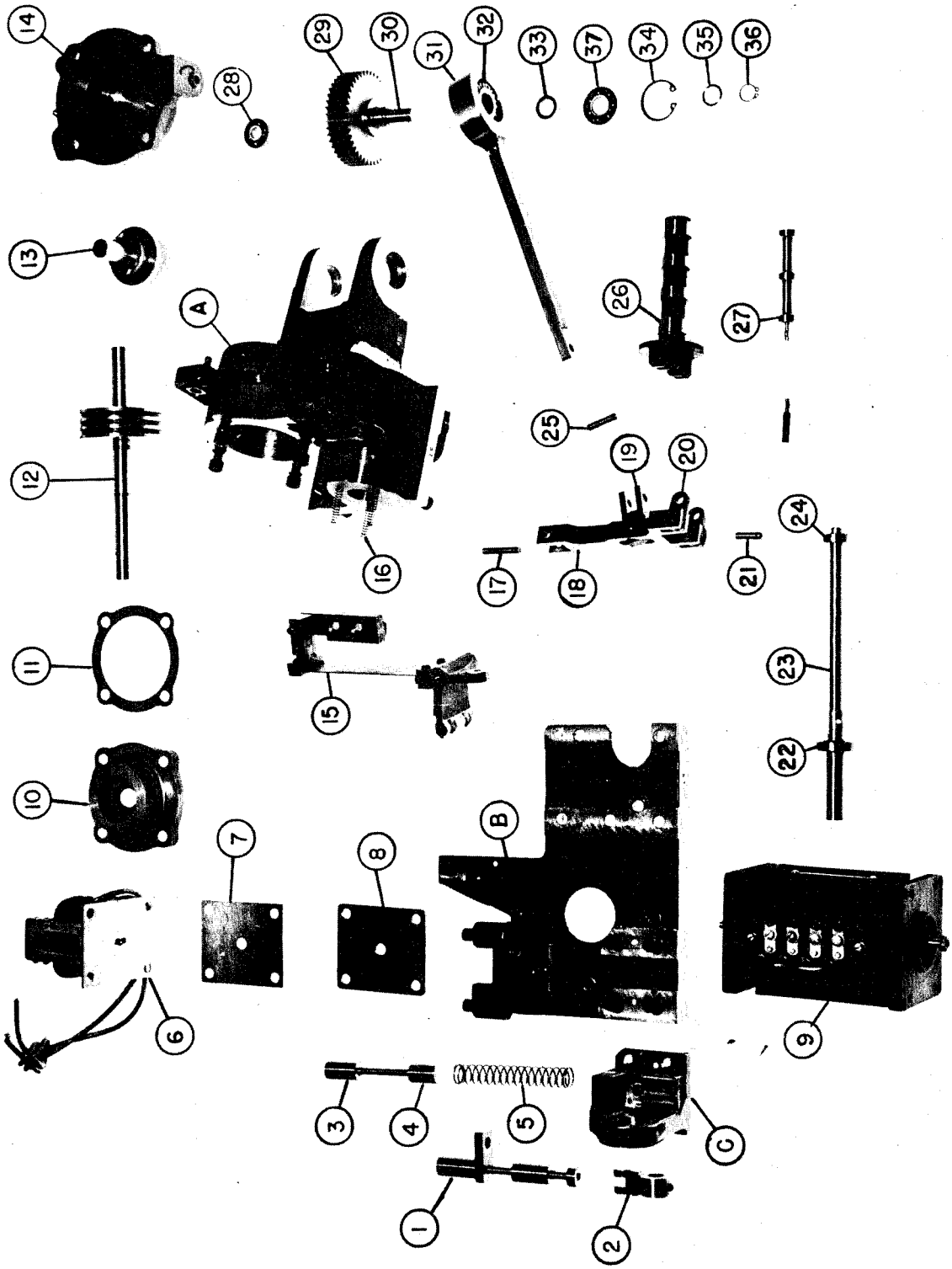


FIGURE 2.35 STROKE CONTROL MECHANISM - DISASSEMBLED

Refer to Fig. 2.35	Name of Part	Part Number	No. Req.
20	Pilot Sleeve Link	6546AP411	2
21	Pin (Pilot Sleeve)	6546AP400	4
22	Ball Bearing - New Departure, or equal	R6	1
23	Limit Stop Shaft	6546AP420	1
24	Ball Bearing - New Departure, or equal	R4	1
25	Pin (Dither)	6546AP399	2
26	Pilot Sleeve	6546BP288	1
27	Pilot Valve Assembly	6546AN038	1
28	Ball Bearing - New Departure, or equal	R4 Class 5	1
29	Dither Gear	6546AP370	1
30	Dither Eccentric	6546AP393	1
31	Dither Eccentric Weldment and Machining Assembly	6546BN047	1
32	Ball Bearing - Norma Hoffman, or equal	U112	1
33	Spacer	6546AP394	1
34	Retaining Ring Truarc	5000-87	2
35	Spacer	6546AP497	1
36	Retaining Ring	5100-37	2
37	Ball Bearing - New Departure, or equal	R6 Class 5	1
	Wire Lead Assembly	6546BP256	1
13	Back Up Piston	6546AP378	1
14	Back Up Cylinder	6546BP264	1
	Rheostat 100 or 250 ohms as required IRC	PR-25	1
	Terminal Strip Jones	142-4	2
	Terminal Strip Jones	141-2	1
Fig. 2.36			
	Limit Stop Assembly	6546DN035	1
	Limit Stop Housing	6546EP022	1
	Limit Stop Housing Cover	6546DP108	1
A	Limit Stop Gear Reduction Assembly	6546CN011	1
1	Pickup Shaft Assembly	6546BN041	1
2	Ball Bearing - New Departure, or equal	488013	1
3	Bearing Retainer	6546AP227	1
4	Idler Gear Shaft Assembly	6546BN040	1
	Gear Plates	6546CP059	1
5	Front Plate	6546BP125	1
6	Spacer	6546AP184	1
7	Rear Plate	6546CP090	1
8	Centering Indicator	6546AP290	1
9	Bearing Retainer	6546AP183	2
10	Intermediate Shaft Assembly	6546BN032	1
12	Cam Plate	6546BP156	1
13	Cam	6546AP226	2

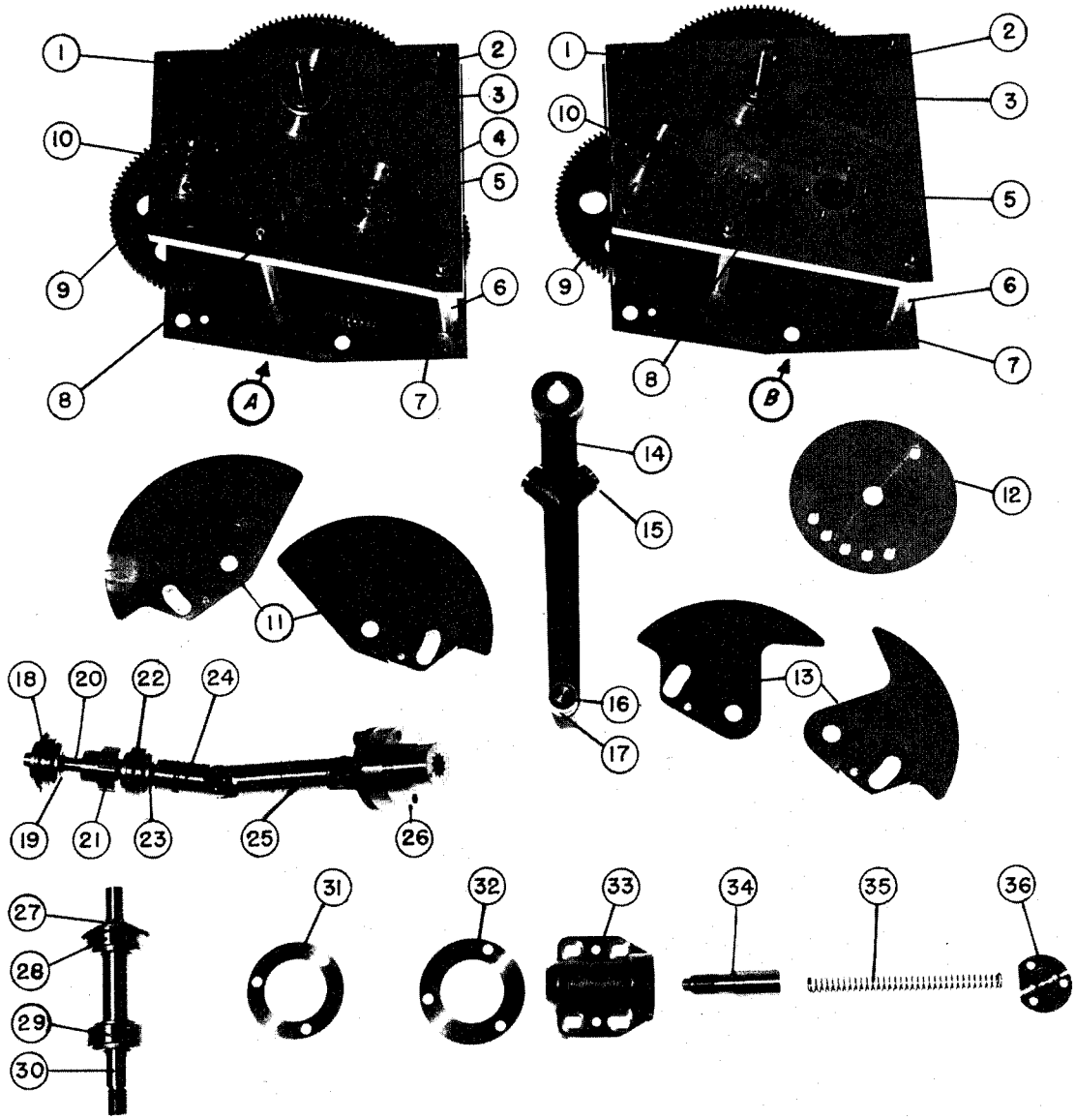


FIGURE 2.36 LIMIT-STOP MECHANISM

Refer to Fig. 2.36	Name of Part	Part Number	No. Req.
11	Cam - Alternate - To be used instead of 6546AP226 if rod travel is reduced by more than six feet	6546AP381	1 or 2
	Limit Stop Arm Assembly	6546BN048	1
14	Limit Stop Arm	6546BP188	1
15	Plunger Bearing Pin	6546AP292	2
16	Limit Stop Pickup Pin	6546AP291	1
17	Ball Bearing Fafnir	K3-L	2
	Input Shaft Assembly	6546BN031	1
18	Ball Bearing - New Departure	488009	1
19	Retaining Ring Truarc	5100-35	2
20	Shaft	6546AP141	1
21	Gear 20P, 18T Boston Gear	NA-18B	1
22	Ball Bearing New Departure	88500	1
23	Retaining Ring Truarc	5100-39	1
24	Universal Joint (Curtis) Boston Gear	C-644B	1
25	Universal Joint Weldment	6546AP285	1
	Universal Joint Coupling Rod	6546AP284	1
26	Limit Stop Pinion Coupling	6546BP189	1
27	Retaining Ring Truarc	5100-50	1
28	Ball Bearing New Departure	488013	1
29	Ball Bearing New Departure	88013	1
30	Shaft	6546BP207	1
31	Bearing Retainer	6546AP283	1
32	Bearing Retainer	6546AP227	1
	Centering Spring Assembly	6546BN049	2
33	Centering Spring Housing	6546BP190	1
34	Centering Spring Plunger	6546AP288	1
35	Centering Spring	6546AP303	1
36	Centering Spring End Cap	6546AP289	
	Emergency Pump Assembly (Identical with Emergency Pump Assembly 6546EN036 except for Limit Stop)	6546EN037	6
	Limit Stop Assembly	6546DN036	1
	Limit Stop Housing	6546EP022	1
	Limit Stop Housing Cover	6546DP108	1
B	Limit Stop Gear Reduction Assembly	6546CN019	1
1	Pickup Shaft Assembly	6546BN041	1
2	Ball Bearing New Departure	488013	1
3	Bearing Retainer	6546AP227	1
	Gear Plate	6546CP059	1
5	Front Plate	6546BP125	1
6	Spacer	6546AP184	1
7	Rear Plate	6546CP090	1

Refer to Fig. 2.36	Name of Part	Part Number	No. Req.
8	Centering Indicator	6546AP290	1
9	Bearing Retainer	6546AP183	2
10	Intermediate Shaft Assembly	6546BN032	1
12	Cam Plate	6546BP156	1
13	Cam	6546AP226	1
11	Cam - Alternate - To be used instead of 6546AP226 if rod travel is reduced by more than six feet. Remainder of parts identical with that of 6546DN035		1 or 2

12. Parts List - Regulating-Rod System - Rod No. 9 - Equipment at Rack Structure - Drawing 6546EN006

Name of Part	Part Number	No. Req.
Rack and Rod Assembly		
See Emergency-Rod System		
Rack Bearing Support Assembly		
See Emergency-Rod System		
Overtravel Stop Assembly		
See Emergency-Rod System		
(Limit Stop Pinion Assembly not used on Rod No. 9)		
Regulating-Rod Power Drive Assembly	6546RN007	1
Base Weldment	6546EP025	1
Bearing Support Assembly	6546CN023	1
Support Weldment	6546CP081	1
Shaft	6546BP192	1
Pillow Block Fafnir 1 1/4 Bore	Type LAK	2
Key	6546AP235	1
Key 1/4 x 1/4 x 2 3/4	---	1
Slip Coupling	6546CP035	1
Gear)	6546CP134	1
Gear)	6546CP135	1
Gear)	6546CP136	1
Gear) Change Gears	6546CP137	1
Gear)	6546CP138	1
Gear)	6546CP139	2
Gear)	6546CP140	1
Motorized Worm Gear Reducer D. O. James Mfg. Co. Position No. 21, Ratio 43:1, 1 h.p., 3 phase, 60 cps, 440 V, Low Starting Current Motor	Size No. 35W	1
Coupling	6546AP388	1
Motor - G.E.Co. 1/6 h.p., 3 phase, 60 cps, 440 V	5K43AC318A	1
Motor Support Weldment	6546CP142	1
Coupling - Boston Gear Works - 1/2 and 5/8 bores	FCB-15	1
Double Worm Gear Reducer - D. O. James Mfg. Co., Ratio 1900:1 Right-Hand Assembly	Size 274W	1

Refer to	Name of Part	Part Number	No. Req.
	Gear	6546BP272	1
	Gear	6546CP141	1
Fig. 2.37	Differential Drive Assembly	6546EN032	1
	Housing Weldment	6546DP110	1
	Cover Weldment	6546EP023	1
	Cap	6546BP215	2
1	Gear	6546BP203	1
2	Shaft	6546BP217	1
3	Sleeve	6546AP321	1
4	Shim	6546AP325	1
5	No. 8 Morse Taper Pin 2 3/4 lg.		1
	Bearing Spacer	6546AP331	1
6	Retainer	6546BP220	1
7	Bearing Case	6546BP218	1
16	Roller Bearing - Timken	Cone-13175 Cup -13318	2
	Gear and Cage Assembly	6546DN040	1
6	Retainer	6546BP220	2
7	Bearing Case	6546BP218	2
8	Retainer	6546BP219	2
9	Shim	6546AP324	2
10	Sleeve	6546AP330	2
12	Shaft	6546BP221	1
13	Cage Weldment	6546CP124	1
14	Gear	6546BP204	1
15	Shaft	6546BP222	1
16	Roller Bearing - Timken	Cone-13175 Cup -13318	4
17	Bearing Spacer	6546AP331	2
18	Roller Bearing - Timken	Cone 375 Cup 374 (adj.)	2
19	Gear	6546AP300	2
20	Gear	6546AP301	2
21	Shim	6546AP323	4
22	Shaft	6546AP322	1
23	Center Block	6546AP329	1
24	Roller Bearing - Timken	Cone-05075 Cup-051858	4
Fig. 2.38			
	Time Delay Relay Assembly	6546BN076	1
	Relay Box		1
	Spacer		2
	Relay Panel Assembly		
	Relay Panel	6546CP249	1
	Capacitor 1 mfd, 600 V d-c Cornell-Dubilier	DYR-6100G	2
	Selenium Rectifier Stack	B6BHN1EM	2
	Time Delay Relay C.P.Clare and Co.	A39299	2

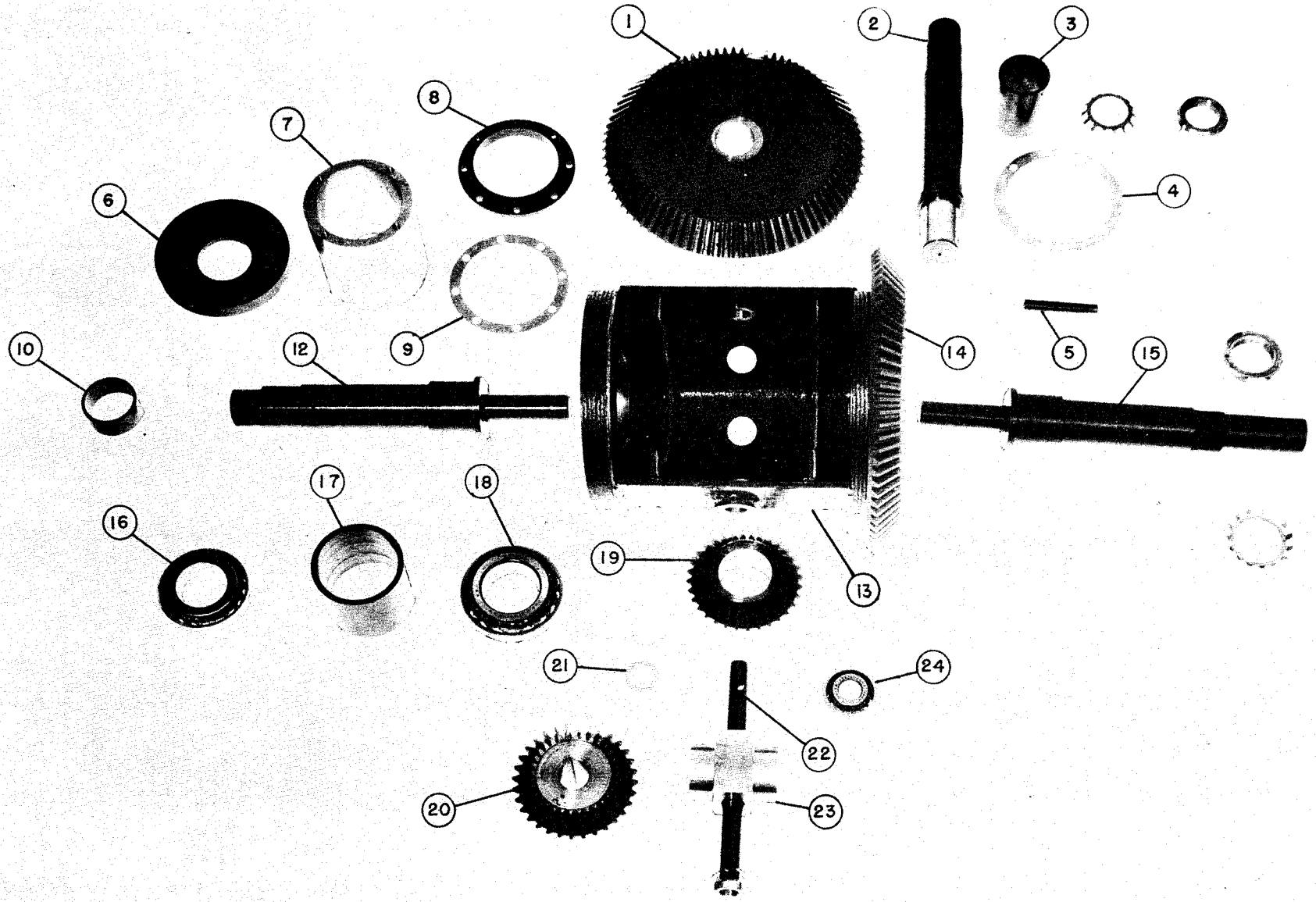


FIGURE 2.37 REGULATING-ROD DIFFERENTIAL DRIVE

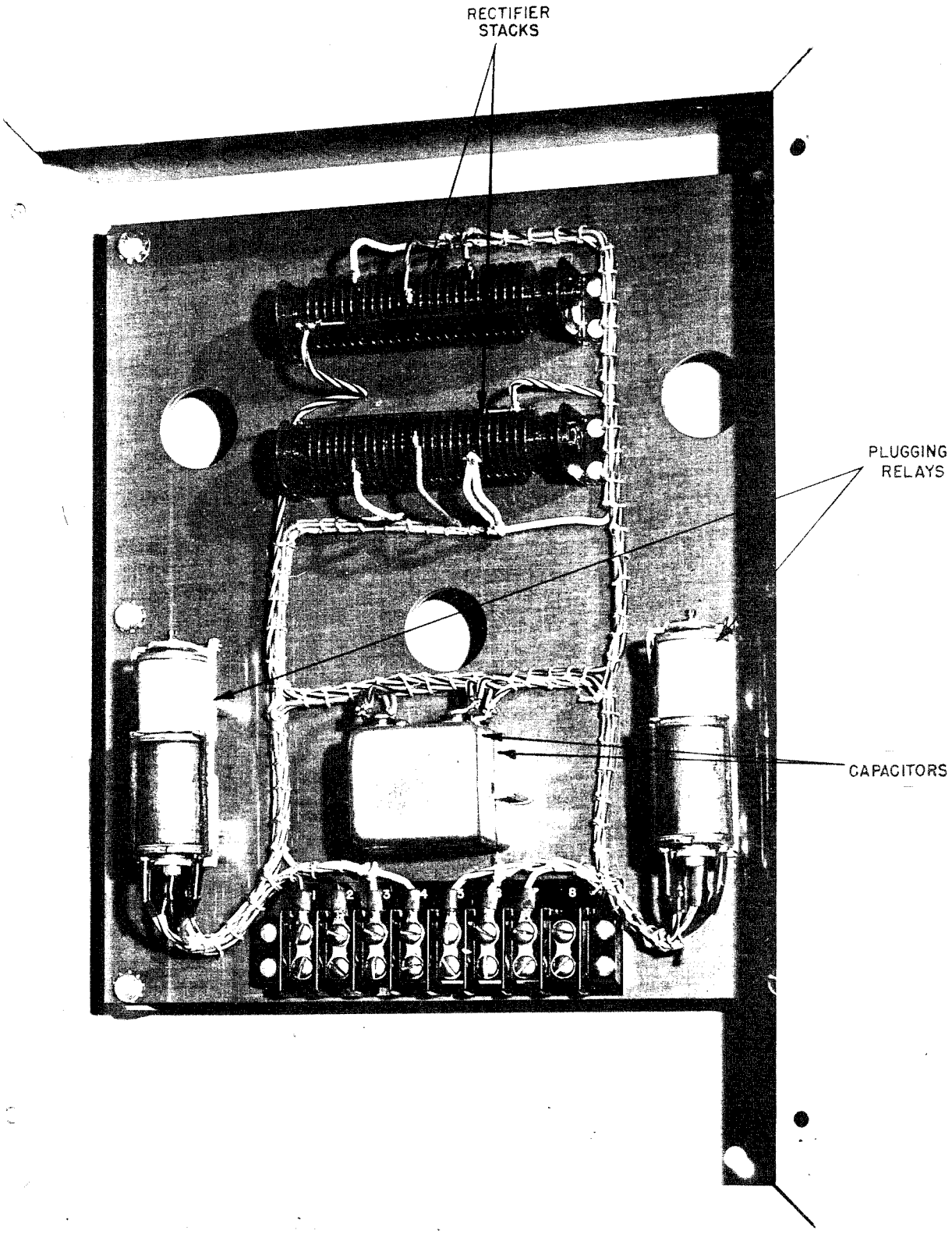


FIGURE 2.38 PLUGGING RELAY ASSEMBLY

13. Parts Lists - Regulating-Rod System - Rod No. 15

For mechanical assembly of components of the rod-drive mechanism, see Parts List for Regulating Rod No. 9.

14. Reference Drawings

Wiring Diagram - Emergency Rod No. 1	6546DK014
Wiring Diagram - Emergency Rod No. 2	6546DK015
Wiring Diagram - Emergency Rod No. 3	6546DK016
Wiring Diagram - Emergency Rod No. 4	6546DK017
Wiring Diagram - Emergency Rod No. 5	6546DK018
Wiring Diagram - Emergency Rod No. 6	6546DK019
Wiring Diagram - Emergency Rod No. 7	6546DK020
Wiring Diagram - Emergency Rod No. 8	6546DK021
Wiring Diagram - Emergency Rod No. 10	6546DK023
Wiring Diagram - Emergency Rod No. 11	6546DK024
Wiring Diagram - Emergency Rod No. 12	6546DK025
Wiring Diagram - Emergency Rod No. 13	6546DK026
Wiring Diagram - Emergency Rod No. 14	6546DK027
Wiring Diagram - Emergency Rod No. 16	6546DK029
Wiring Diagram Emergency-Rod Drive Motors	6546DK013
Elementary Diagram Regulating Rod No. 9 Drive Motors	6546CK023
Wiring Diagram - Regulating Rod No. 9	6546CK022
Automatic Power Regulator Power Supply E40	6546DK041
Elementary Diagram Reactor Automatic Power Regulator	6546DK035
Automatic Power Regulator Amplifier	6546CK043
Automatic Power Regulator Amplifier E41	6546EN047
Automatic Power Regulator Power Supply E40	6546EN046

15. Engineering Report References, D.I.C. 6546, M.I.T.

Emergency-Rod Electric Drive Motor, Tachometer, and Motor Control, Engineering Report No. 37

Energy Conversion System of the Type Proposed in Engineering Report No. 3, Study of Gearing Requirements of an, Engineering Report No. 4

Energy Storage for Emergency Operation of Control Rods, Comparative Study of Methods of Providing, Engineering Report No. 3

Flywheel Design for Emergency Rods, Engineering Report No. 26

Manual Drives, Design of, Engineering Report No. 17

Overtravel Stop and Drive Pinion, Control Rod, Engineering Report No. 25

Pump and Motor for Emergency Rods, Hydraulic, Engineering Report No. 32

Racks, Control Rod, Design of,
Engineering Report No. 21

Stroke Control, Hydraulic Pump, for Emergency Rods,
Engineering Report No. 33

Stroking Forces, Dynamic, of Oilgear AH311 Pump,
Engineering Report No. 10

Supports, Rack Bearing, Design of,
Engineering Report No. 13

Regulating-Rod Drive,
Engineering Report No. 28

Reversal Time and Backlash of 1/6-Horsepower Reduction Motor Driving D. O. James Reducer under No Load Conditions,
Engineering Report No. 38, Part 1

Coasting Time and Power Consumption of Above Combination under Load Conditions,
Engineering Report No. 38, Part 2

Automatic Power Regulation for Brookhaven Reactor,
Engineering Report No. 57

Friction Coefficient between Graphite and a Metal Surface,
Engineering Report No. 9

Regulating-Rod Position Transmitter, Design of,
Engineering Report No. 23

Solution of the Differential Equations of a Pile,
Engineering Report No. 16

CHAPTER III

ROD-POSITION INSTRUMENTATION

1. Introduction

Safety in operation, adequate control procedure, and the collection of experimental data at the Brookhaven nuclear reactor are dependent on the rod-position instrumentation. Various indications and records of position for each of the 16 control rods are provided to meet these requirements.

Rod-position data are provided in the control room by four groups of instruments, which are functionally distinct. Designations and functions of the four are as follows:

Position indicators for the regulating rods - provide precise indication of the position of each of the two regulating rods.

Position indicators for the emergency rods - provide precise indication of the position of each of the 14 emergency rods.

Coarse rod-position indicators for all rods - provide approximate, easily read indications of the positions of the 16 rods.

Rod-position recorders for all rods - provide graphical records of the positions of each of the 16 rods.

Rod-position data originate at the instrument pinions on the control-rod structure. One pinion is driven by each rack. Each instrument-pinion shaft is directly connected to the input shaft of

a rod-position transmitter, from which electrical signals are transmitted to the indicating and recording instruments in the control room. In each of the transmitters, an appropriate gear train drives the electrical signaling devices for the three systems applicable to its particular rod. Power for all systems is furnished at 115 volts, single phase, 60 cycles per second from the instrument power generator.

The coarse rod-position indicators are equipped with separate indicating lights to show when any rod has reached its limit of travel in either direction. Limit switches with roller arms bearing on the racks provide signals for these indicating lights.

The indicating and recording apparatus are adjusted to read zero for a rod insertion (in the graphite) of six inches (15.24 cm.). Normal operation of the pile is expected to take place in the range between 5'6" and 25'6" of rod insertion, which will be in the range of instrument readings between 1.524 meters and 7.620 meters. Full travel of a rod is considered to be 25 feet or 7.620 meters.

2. Regulating-Rod Position Indicators - System Description

The regulating-rod position indicators were designed to provide a reading of rod position with a static accuracy of $\pm$ 0.25 millimeter.

Each regulating-rod position indicator consists of the following components:

An instrument pinion for sensing rod position through the rack attached to the rod.

A rod-position transmitter, located on the rod structure, containing a pair of synchro transmitters and necessary gearing.

An indicating unit containing two synchro control-transformers, an electric servo-motor, indicating dials, and necessary gearing. This assembly is mounted on operator's console in the control room. An amplifier for modifying the signals provided by the synchro control-transformers for use by the servo-motor. This apparatus is located in the equipment room.

The system arrangement is shown schematically in Figure 3.1. Rack movement is transmitted through the instrument pinion to the transmitter input shaft. Inside the transmitter this shaft is directly coupled to the fine synchro-generator and, through a reducing gear train, to the coarse synchro-generator. Additional gears (not shown in Figure 3.1) transmit input shaft rotation to components of the other rod-position instruments. Relative displacements in the transmitter are shown in the following table.

Relative Displacements, Regulating-Rod Position Transmitter

Shaft	Revolutions per Revolution of Instrument Pinion	Revolutions Per in. of Rod Travel	Revolutions Per cm. of Rod Travel	Revolutions For Full Rod Travel (25')
Instrument Pinion	- - -	0.1592	0.0627	47.77
Fine Synchro	1	0.1592	0.0627	47.77
Coarse Synchro	0.04	0.00637	0.00251	1.91

In the indicating unit, three dials, designated METERS, DECIMETERS, and CENTIMETERS, respectively, indicate rod insertion into the reactor. The

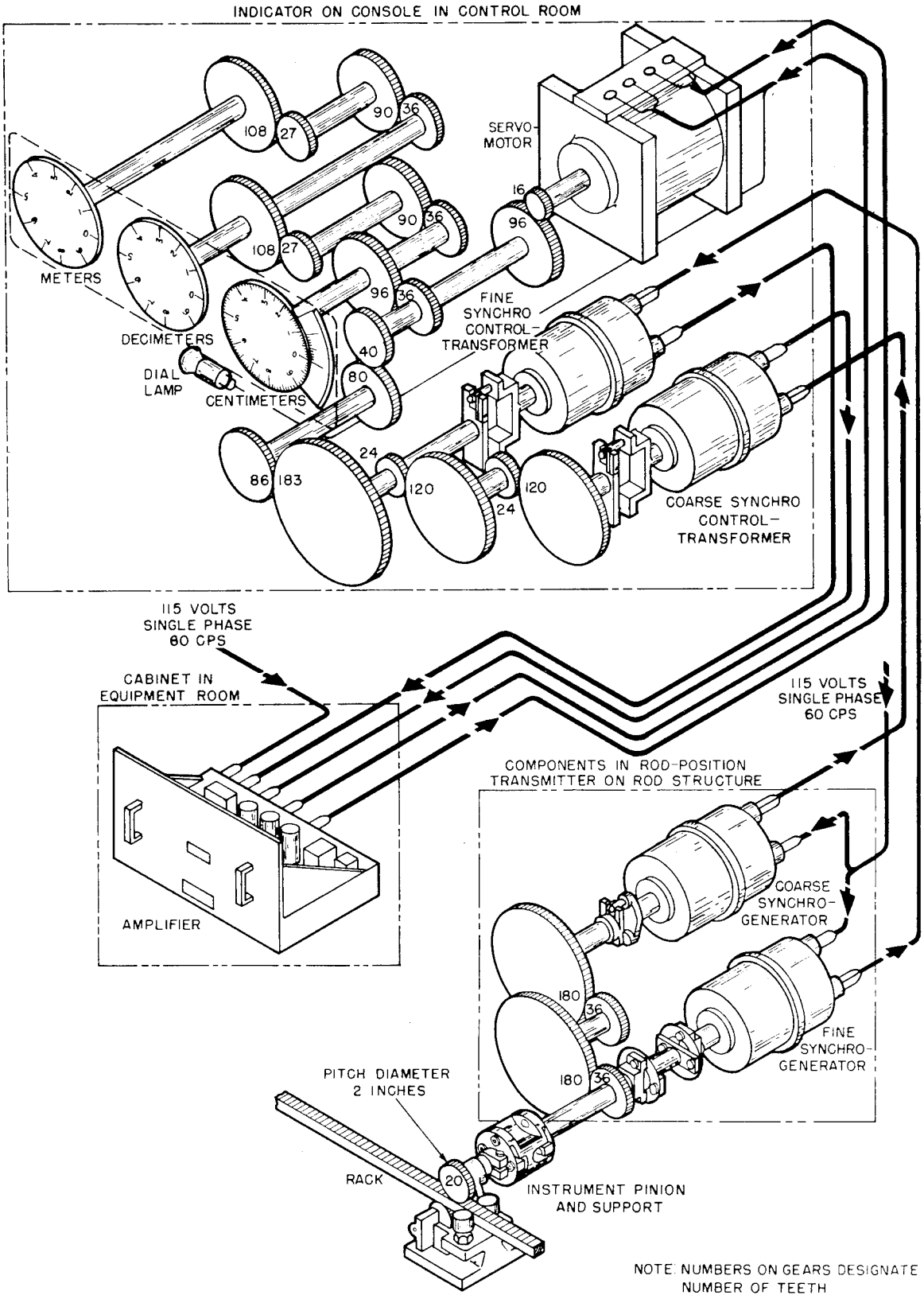


FIGURE 3.1 REGULATING-ROD POSITION INDICATING SYSTEM

left-hand dial has 10 numbered graduations, each representing one meter of rod travel. The center dial is similarly graduated in decimeters. The right-hand dial has 10 numbered graduations, each representing one centimeter, and intermediate, unnumbered graduations representing millimeters. A vernier at this dial permits reading to 0.1 millimeter. The dials are illuminated by a 115-volt lamp, which is energized from the servo-motor reference-field circuit. The servo-motor drives the indicating dials through a gear train, and dial rotation is fed back through the drive train to the synchro control-transformer shafts. Relative displacements in the indicator are given in the following table.

Relative Displacements, Regulating-Rod Position Indicator

Shaft	Revolutions per Revolution of Centimeter Dial	Revolutions Per in. of Rod Travel	Revolutions Per cm. of Rod Travel	Revolutions For Full Rod Travel (25')
Centimeter Dial	- - -	0.254	0.100	76.2
Decimeter Dial	0.10	0.0254	0.010	7.62
Meter Dial	0.010	0.00254	0.001	0.762
Servo-Motor	16	4.064	1.600	1219
Fine Control-Transformer	0.628	0.1592	0.0628	47.77
Coarse Control-Transformer	0.0251	0.00637	0.00251	1.91

The amplifier has an automatic fine-to-coarse switching circuit, five stages of amplification, and a self-contained power supply. Two manual adjustments are provided, one to set the gain of the amplifier, the other to balance electrical interference of power frequency.

In normal operation, indicating dial movement is controlled by the fine-synchro system through the amplifier and the servo-motor. Rod movement causes rotation of the synchro-generator. The resulting error voltage from the control-transformer rotor is impressed on the amplifier. The amplifier output drives the servo-motor to turn the dials in the direction corresponding to rod movement, and dial rotation is fed back mechanically to the control-transformer rotor, turning the rotor to reduce the error voltage.

The coarse synchro system acts as a monitor to prevent loss of synchronism if, for any reason, the error exceeds the range of the fine system. In this event, a relay-operated switch in the amplifier cuts out the fine system and cuts in the coarse system. The latter then controls dial movement until the error is reduced to less than 75 degrees on the fine synchro, when the relay switch is shifted back, and the fine system assumes control.

3. Regulating-Rod Position Indicators - Component Description

3a. Instrument Pinion and Support - The instrument pinion-and-support assembly is shown pictorially in Figure 3.2. This assembly is supported by a wedge-plate weldment and adjustable wedge assembly similar to that for the rack bearing support shown in Figure 2.3, Ch. II.

A disassembled view of the pinion-and-support assembly is given in Figure 3.26.

3b. Rod-Position Transmitter - The regulating-rod position transmitters contain elements of the coarse rod-position indicators, rod-position recorders, and the automatic power-level regulator, as well as of the regulating-rod position indicator. This transmitter is shown pictorially in Figure 3.3. Gearing and instrument arrangement and

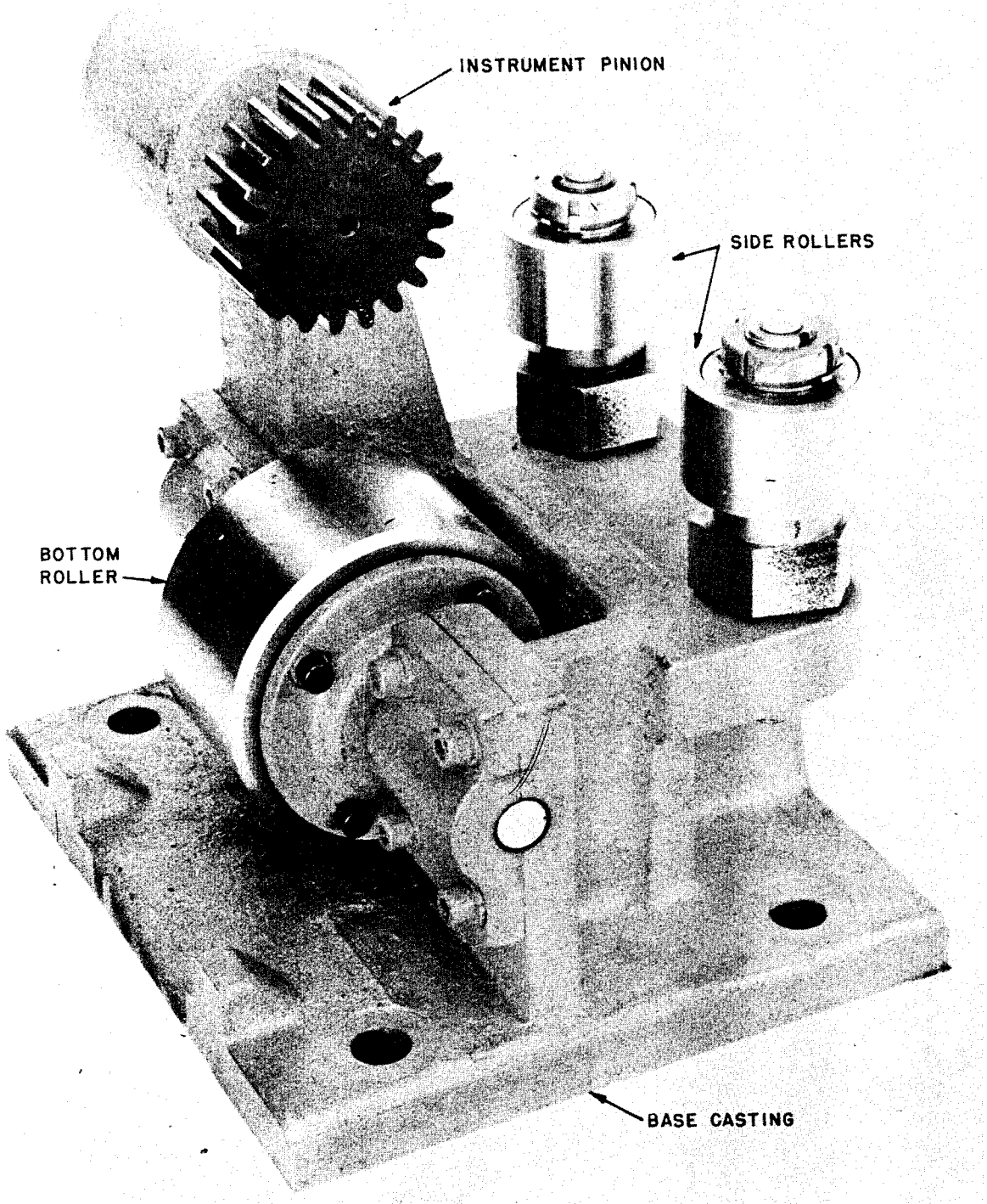


FIGURE 3.2 INSTRUMENT PINION SUPPORT

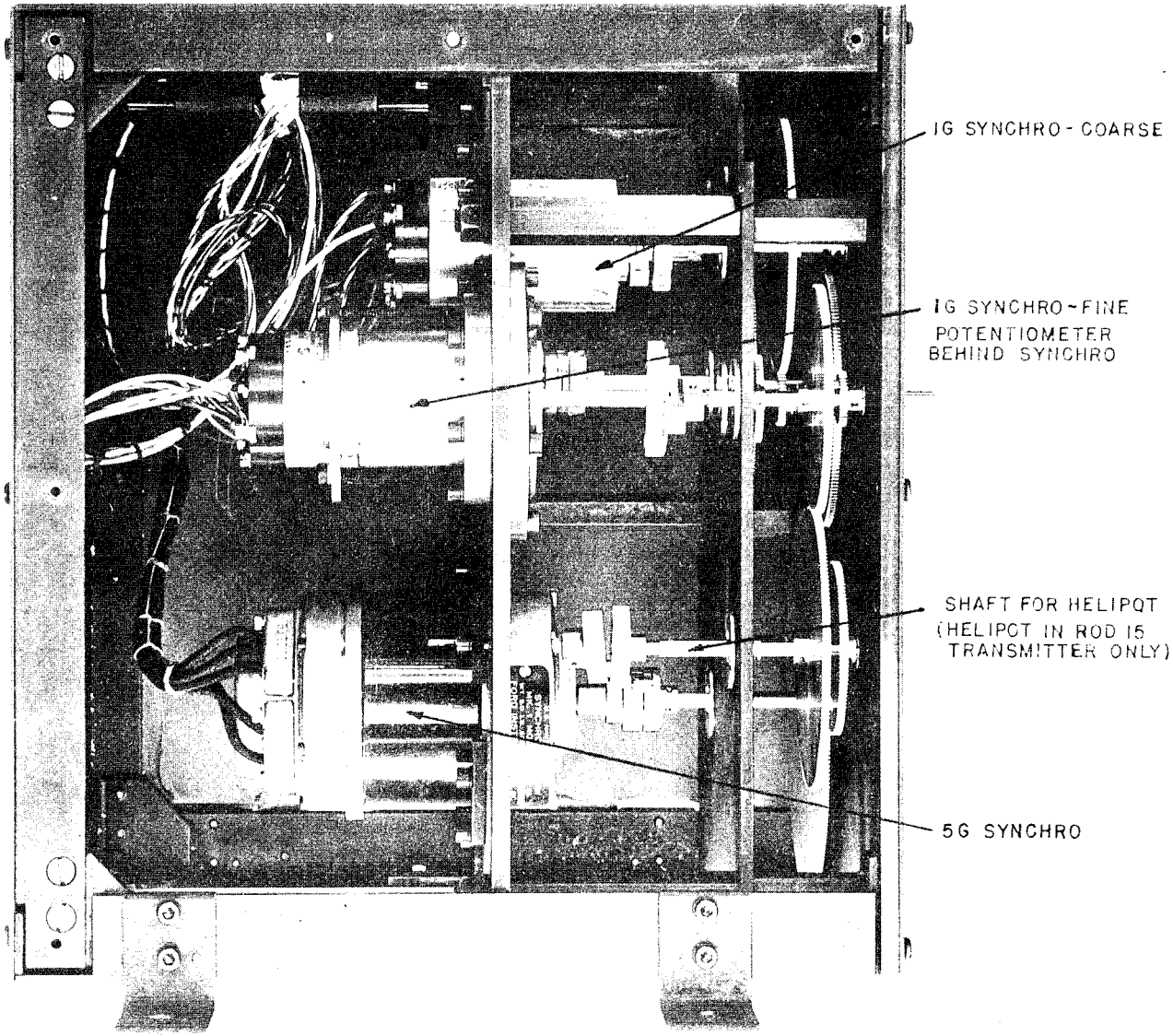


FIGURE 3.3 REGULATING-ROD NO. 9 POSITION TRANSMITTER

interior wiring for Rod No. 15 are shown schematically in Figure 3.4. The transmitter for Rod No. 9 is identical, except that the Beckman helipot is not required. The disassembled parts of a transmitter appear in Figure 3.27.

The electrical elements of the regulating-rod position indicator in this transmitter are the fine and coarse synchro-generators, U. S. Navy type Mark 5, size 1G.

Because of the high degree of accuracy of data transmission required by this system, the mechanical components of the transmitter were selected and designed to keep backlash within required limits. All gears are commercial precision gears manufactured by the Reeves Instrument Company. Spring-type anti-backlash couplings connect the synchro-generators to the gearing. The coupling between the instrument pinion and the transmitter is also of an anti-backlash type.

3c. Position-Indicating Units - The two indicating units are located on the right wing of the console and appear as shown in Figure 3.5. A rear view of one unit is shown in Figure 3.6. Gearing and instrument arrangement and interior wiring for Rod No. 9 are shown schematically in Figure 3.7. Disassembled parts are presented in Figure 3.28.

The two dial mechanisms are similar and are supported by a mounting frame which is bolted to the console panel. An aluminum shield at the back and a clip-on cover in front are attached to the mounting frame to enclose the mechanisms.

The control-transformers are U. S. Navy type, Mark 5, size 1CT. They are flange-mounted to facilitate zeroing and are connected to the appropriate gear shafts by spring-type anti-backlash couplings.

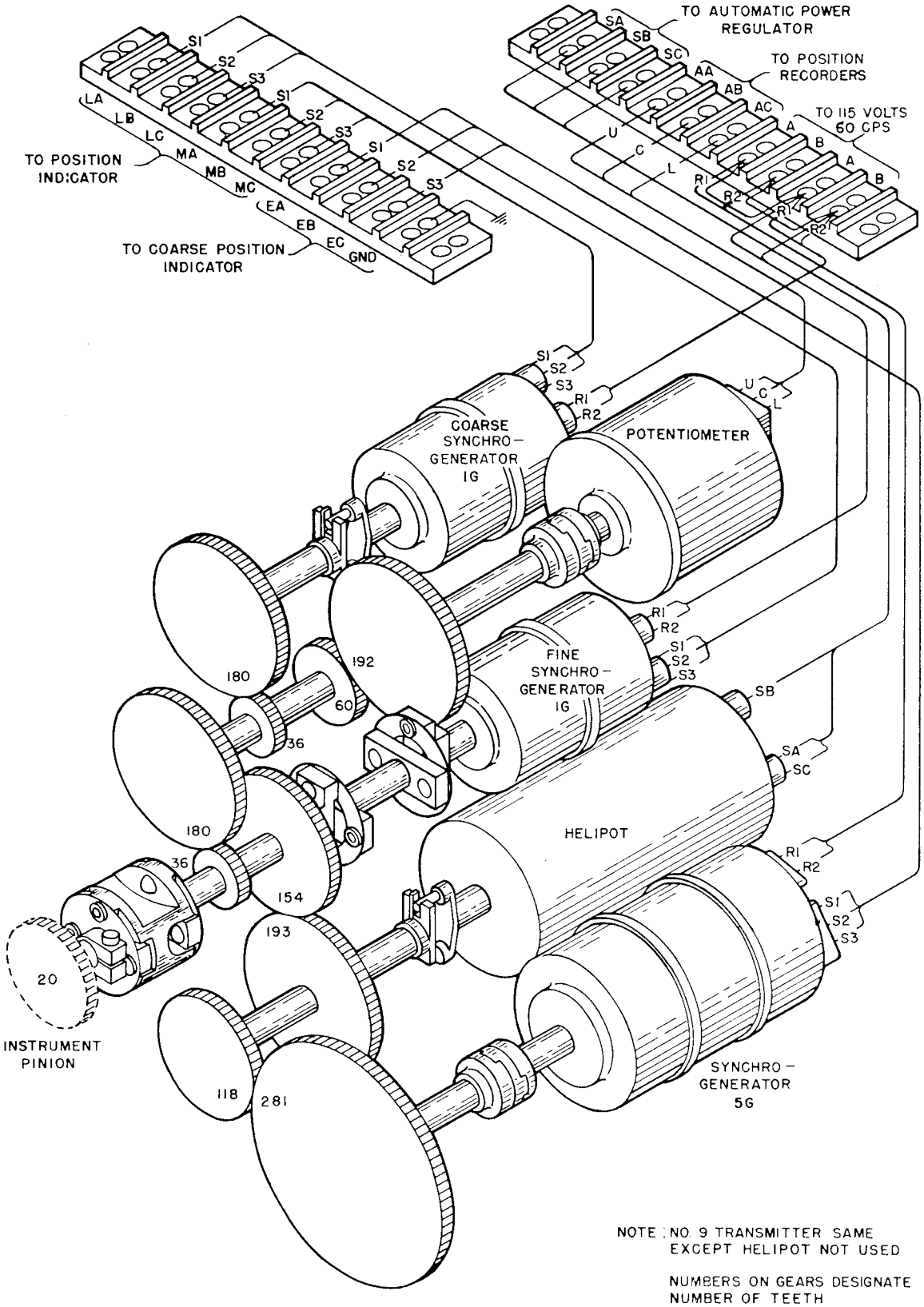


FIGURE 3.4 REGULATING-ROD POSITION TRANSMITTER - ROD NO. 15

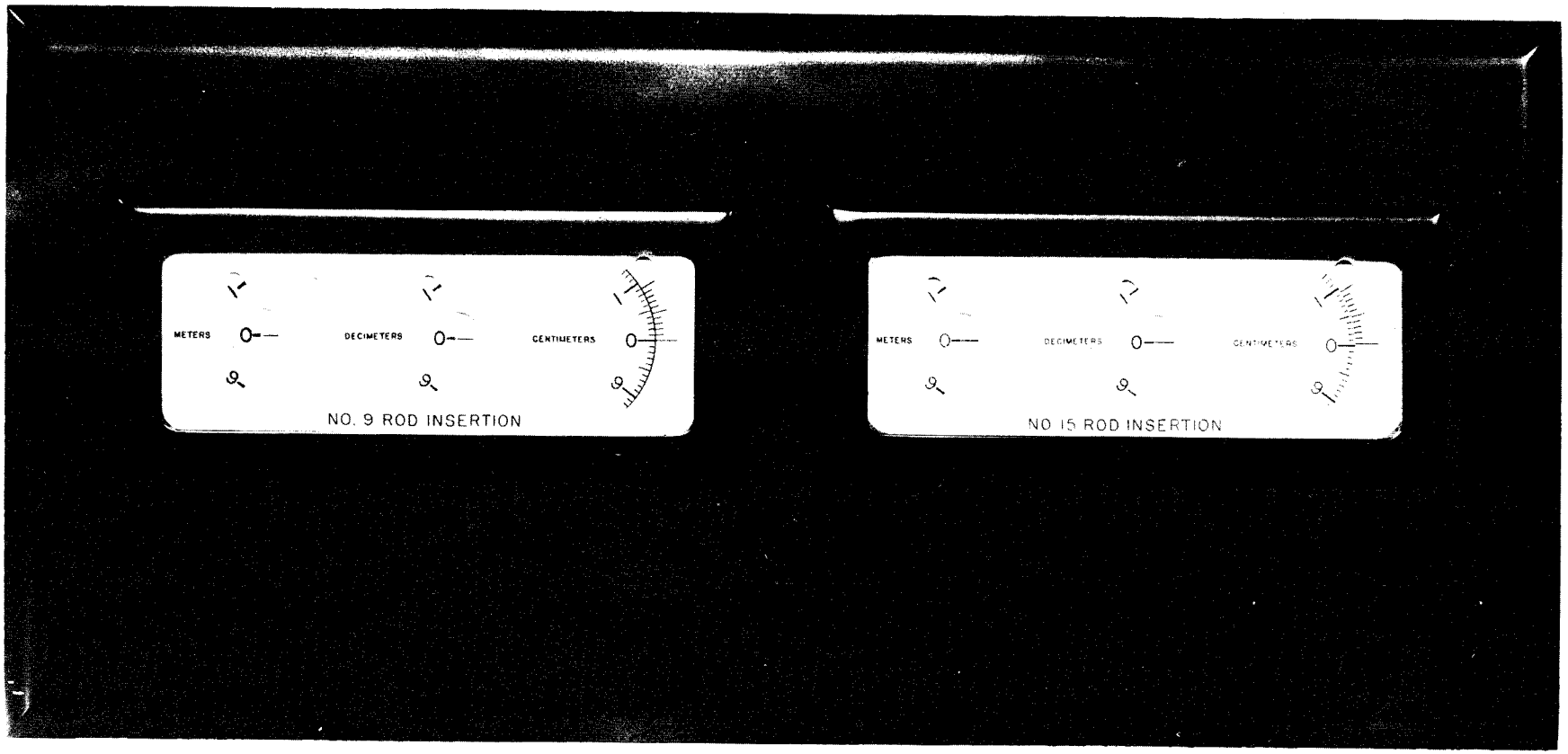


FIGURE 3.5 REGULATING-ROD POSITION INDICATING UNIT

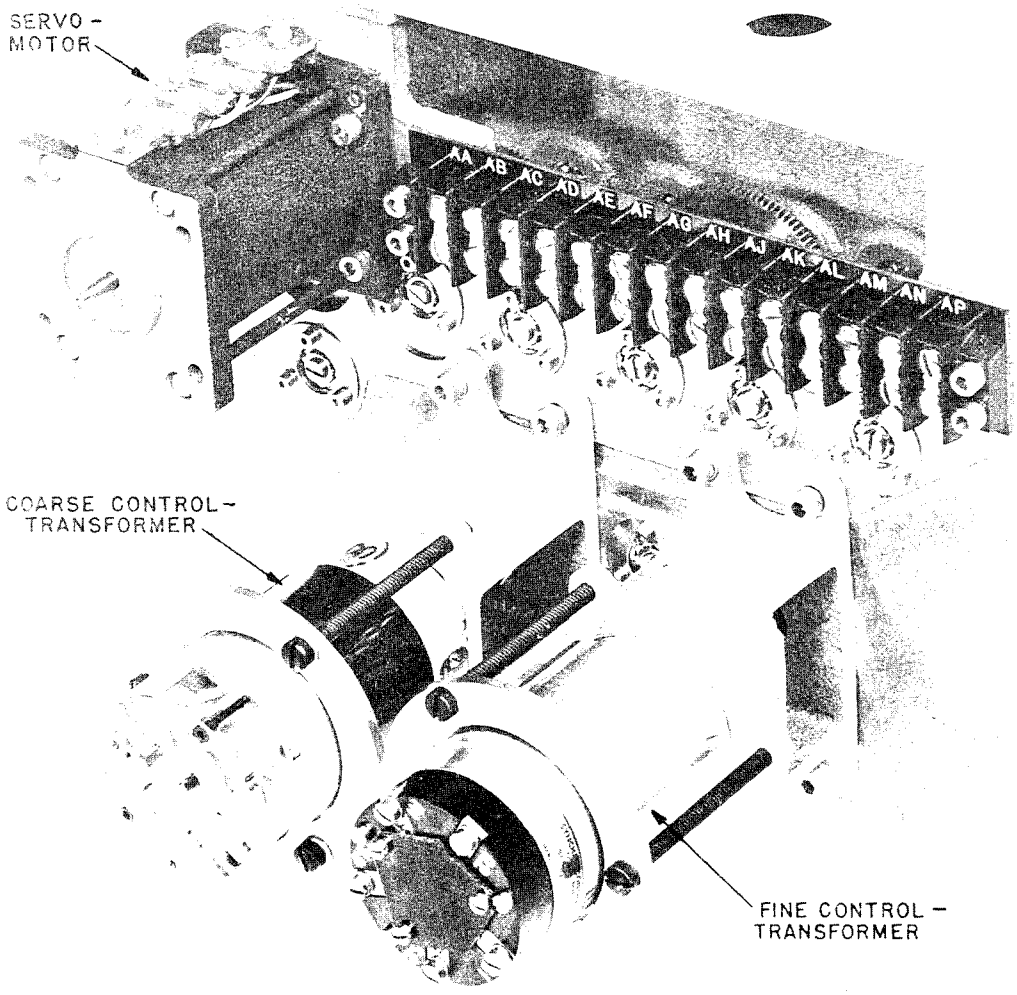
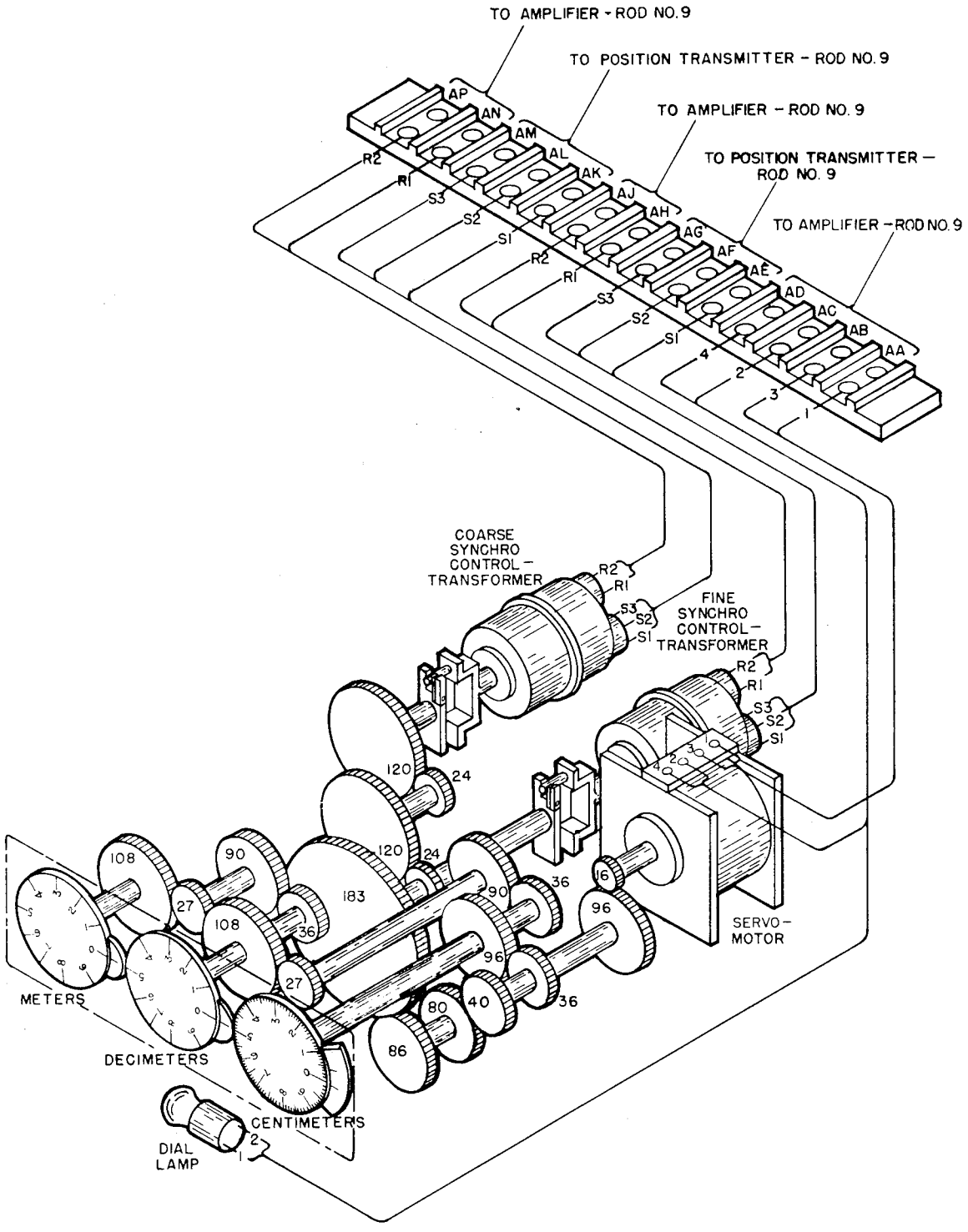


FIGURE 3.6 REGULATING-ROD POSITION INDICATING UNIT - REAR



NOTE: NUMBERS ON GEARS DESIGNATE NUMBER OF TEETH

FIGURE 3.7 REGULATING-ROD POSITION INDICATING UNIT - ROD NO.9

The servo-motor is a two-phase, 115-volt motor, Diehl Manufacturing Company, Type FPE 25-11.

All gears are precision spur gears, manufactured by the Reeves Instrument Company. At assembly, gear hubs are secured to their shafts by setscrews, but, after dial synchronization, are permanently fastened by taper pins. All shafts are supported in ball-bearing mountings.

3d. Amplifier - The amplifier for each regulating-rod position indicator contains its power supply on its own chassis. These units are located in cabinet TB131 in the equipment room. They are illustrated in Figure 3.8. The circuit is shown in Figure 3.9.

In the power supply, a full-wave rectifier with a single-section choke-input filter provides d-c working voltage. Unregulated power is supplied directly to the final stage of the amplifier, but a 150-volt regulating network supplies power to the rest of the amplifier.

The five-stage amplifier uses two dual triodes with a final push-pull stage of beam-power pentodes that are transformer-coupled to the servo-motor. The input stage includes an adjustable gain control and a servo-stabilizing tuned network. Coupling to the second stage includes a resistance-capacitance noise filter. Voltage of proper phase is introduced into the cathode of the second stage to reduce output voltage to zero when the input terminals are shorted. With the exception of the third stage, which is direct-coupled to a phase-inverter feeding the two signal grids of the output stage in push-pull, the amplifier uses resistance-capacitance coupling.

A synchronizing relay switches from the fine to the coarse synchro as dictated by the magnitude of the coarse-synchro signal. A

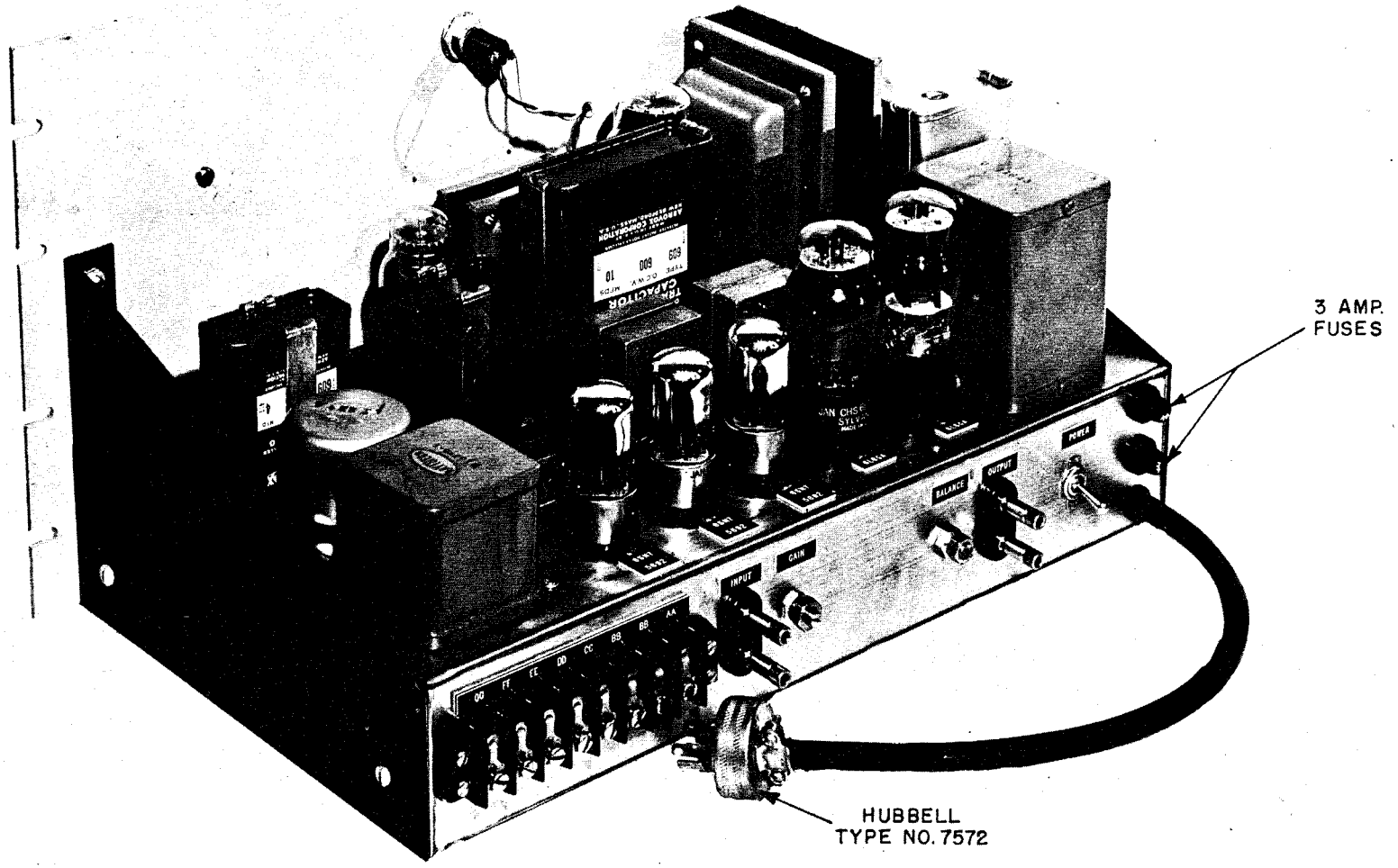
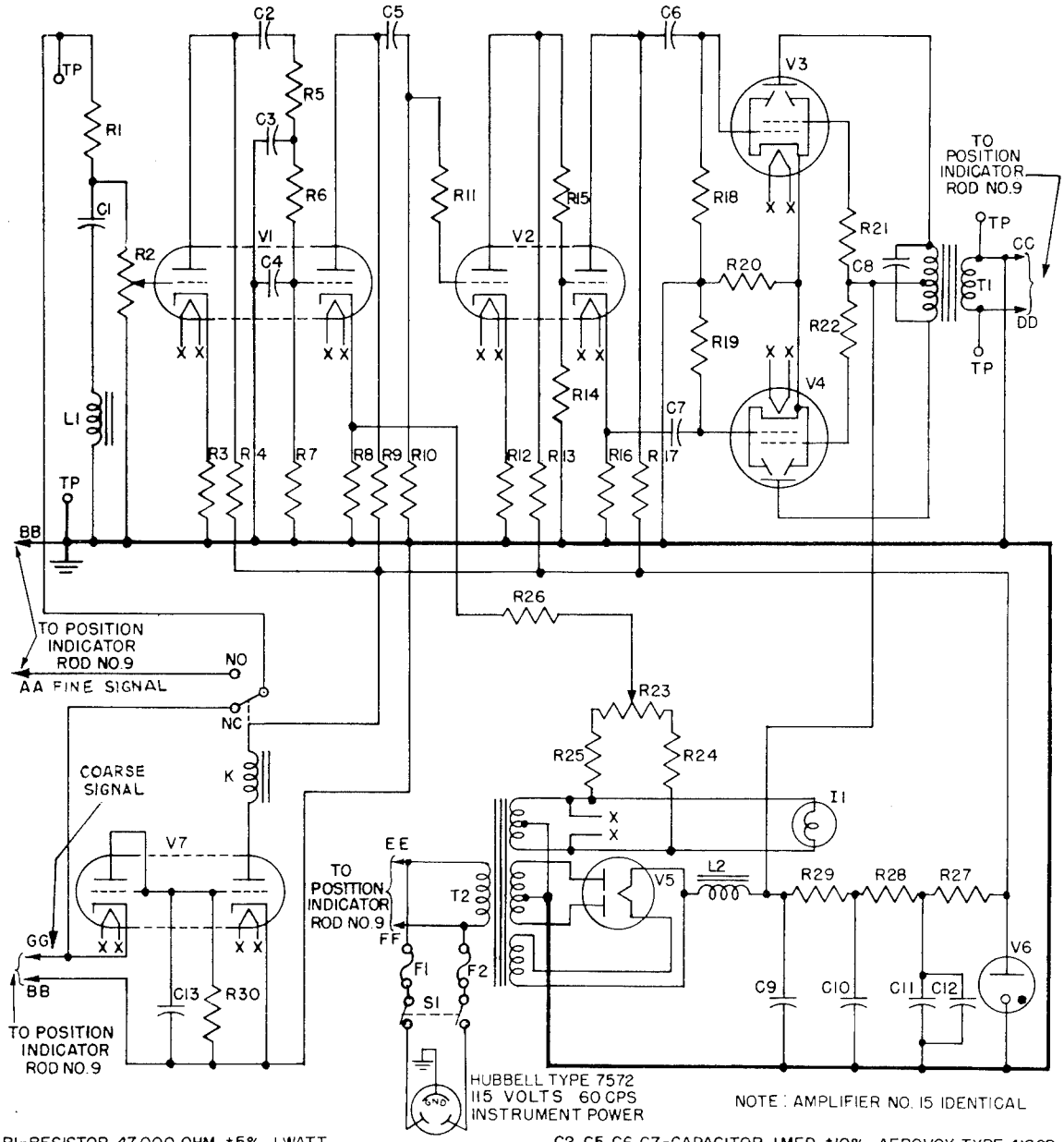


FIGURE 3.8 AMPLIFIER FOR REGULATING-ROD POSITION INDICATOR



R1-RESISTOR, 47,000 OHM, ±5%, 1 WATT
R2-POTENTIOMETER, 500,000 OHM, ±5%, 1 WATT
R3, R8, R12, R24, R25-RESISTOR, 4700 OHM, ±5%, 1WATT
R4, R9, R13-RESISTOR, 100,000 OHM, ±5%, 1WATT
R5, R6-RESISTOR, 33,000 OHM, ±5%, 1 WATT
R7, R10, R11, R30-RESISTOR, 470,000 OHM, ±5%, 1 WATT
R14, R15-RESISTOR, 1 MEGOHM, ±5%, 1 WATT
R16, R17-RESISTOR, 27,000 OHM, ±5%, 1 WATT
R18, R19-RESISTOR, 220,000 OHM, ±5%, 1 WATT
R20-RESISTOR, 100,000, OHM, ±5%, 5 WATTS
R21, R22-RESISTOR, 100 OHM, ±5%, 1 WATT
R23-POTENTIOMETER, 600 OHM, ±10%, 1 WATT
R26-RESISTOR, 10,000 OHM, ±5%, 1 WATT
R27-RESISTOR, 1000 OHM, ±5%, 5 WATTS
R28-RESISTOR, 1500 OHM, ±5%, 5 WATTS
R29-RESISTOR, 2500 OHM, ±5%, 5 WATTS
C1-THREE CAPACITORS: TWO SMALL MOLDED AND ONE .05 MFD, CAN TYPE (AEROVOX TYPE 418 B) SELECTED TO RESONATE WITH CHOKE L1 AT 1.25 VOLTS, 60 CPS, (REQUIRED CAPACITY APPROX. 0.1 MFD)

C2, C5, C6, C7-CAPACITOR, 1 MFD, ±10%, AEROVOX TYPE 418CB
C3, C4-CAPACITOR, DUAL TYPE, 0.1-0.1 MFD, C.D. TYPE DYR6011
C8-CAPACITOR 0.25 MFD, ±10%, C.D. TYPE DYR6025
C9-CAPACITOR 10MFD, ±10%, AEROVOX TYPE 609
C10, C11-CAPACITOR 4 MFD, ±10%, AEROVOX TYPE 609
C12-CAPACITOR, 6MFD, ±10%, C.D. TYPE TJ6060G
C13-CAPACITOR, 0.1 MFD, ±10%, AEROVOX TYPE 618B
L1-INDUCTOR, RAYTHEON TYPE M-10750-1
L2-INDUCTOR, THORDARSON TYPE T-20C54
T1-TRANSFORMER, RAYTHEON TYPE M11645-1
T2-TRANSFORMER, THORDARSON TYPE T-22R33
V1, V2, V7-VACUUM TUBE, TYPE 6SN7 OR TYPE 5692
V3, V4-VACUUM TUBE, TYPE 6L6GA
V5-VACUUM TUBE, TYPE 5U4G
V6-VOLTAGE REGULATOR TUBE, VR-150 (OD3)
I1-PILOT LAMP, GE #47
S1-SWITCH, CUTLER-HAMMER TYPE 7360K8
F1, F2-FUSE BUS, 3AG, 3AMP
K-RELAY, SIGMA TYPE 4A

FIGURE 3.9 AMPLIFIER FOR REGULATING-ROD POSITION INDICATOR - ROD NO. 9

plate-current relay in series with one half of a dual triode is normally energized, maintaining the fine-signal input to the amplifier. The second half of the triode, connected as a diode, rectifies negative half-cycles of the coarse synchro-control-transformer voltage. When this rectified voltage, smoothed by a resistance-capacitance filter, exceeds approximately 4.0 volts, the applied negative voltage on the grid of the switching section of the tube reduces the current in the relay coil below the holding level. The coarse signal is then supplied to the amplifier. Decay of the coarse signal restores the amplifier input circuit to the fine signal.

4. Regulating-Rod Position Indicators - Adjustment

The procedure for adjustment of the indicator is as follows:

4a. Disconnect one side of each motor field and one side of the control-transformer at the amplifier terminal block. Short the input test points.

4b. Adjust the balance control for a minimum voltage at the output test terminals. Tighten the locking nut while the meter is attached.

4c. Remove the short from the input test points.

4d. Apply 1 volt, 60 cycles per second to the input terminals and adjust the gain control to produce 60 volts at the output test terminals.

4e. Reconnect the motor fields and control-transformers.

4f. Set the control rod at any known position.

4g. Remove vacuum tube V7 (Figure 3.9). Unit should operate normally except for low sensitivity. Rotate stator of coarse control-

transformer in the indicating unit until dials read the known rod position.

4h. Replace vacuum tube V7 to restore synchronizing circuit to normal operation. Rotate stator of fine control-transformer until dials again read the known rod position.

These are the general steps required to synchronize the unit.

5. Emergency-Rod Position Indicators - System Description

The emergency-rod position indicators were designed to provide a reading of rod position with a static accuracy of plus or minus one millimeter.

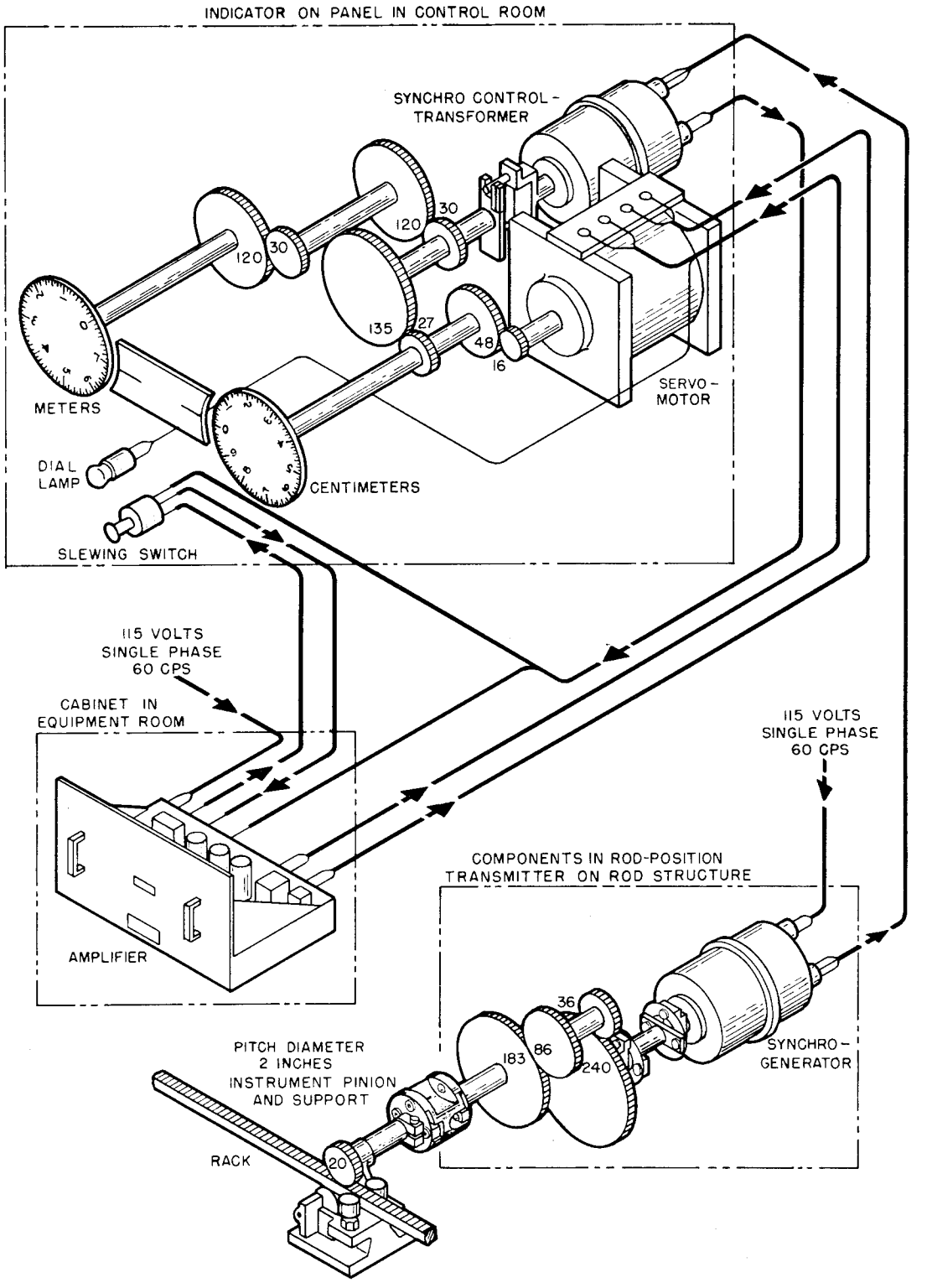
The arrangement of the system is shown schematically in Figure 3.10. It is similar to the regulating-rod position indicating system, but is simpler because of the less severe accuracy requirement. The system has a single electrical data transmission circuit since, in this system, synchronization is effected manually. Each emergency-rod position indicator consists of the following components:

An instrument pinion for sensing rod position through the rack attached to the rod.

A rod-position transmitter, located on the rod structure, containing a synchro-generator and necessary gearing.

An indicating unit containing a synchro control-transformer, a servo-motor, indicating dials, and necessary gearing. This assembly is located on Control Panel M in the control room.

An amplifier for modifying the signal provided by the synchro control-transformer for use by the servo-motor. This apparatus is located in the equipment room.



NOTE: NUMBERS ON GEARS DESIGNATE NUMBER OF TEETH

FIGURE 3.10 EMERGENCY-ROD POSITION INDICATOR

The arrangement of the instrument pinion and its connection to the transmitter shaft are similar to that of the regulating-rod indicators. Inside the transmitter, the single synchro-generator is driven from the input shaft through a gear train, and additional gears (not shown in Figure 3.10) transmit shaft rotation to components of the other rod-position instruments. Relative displacements are shown in the following Table.

Relative Displacements,
Emergency-Rod-Position-Indicator Components
in the Transmitter

Shaft	Revolutions per Revolution of Instrument Pinion	Revolutions Per in. of Rod Travel	Revolutions Per cm. of Rod Travel	Revolutions For Full Rod Travel (25')
Instrument Pinion	- -	0.1592	0.0627	47.77
Synchro Generator	0.319	0.0508	0.0200	15.24

The 14 indicating units are mounted in pairs in section seven of Control Panel M in the control room. Each pair is contained in a single base casting, the seven assemblies being arranged in a vertical row. The front of the panel is closed by a metal door having 14 windows through which the indicating dials can be observed. Appropriate labels identify the rods to which the individual indicators belong, and also indicate the dial units.

The left-hand dial is labeled METERS: it has eight numbered graduations, each representing one meter of rod travel, and intermediate graduations representing decimeters.

The right-hand dial of each indicator is labeled CENTIMETERS and has 10 numbered graduations, each representing one centimeter of rod travel. Intermediate graduations represent millimeters. No vernier is provided.

Each pair of dials is illuminated by a 115-volt lamp, which is energized from the servo-motor reference-field circuit.

The servo-motor drives the indicating dials through a gear train, and dial rotation is fed back mechanically to the control-transformer. Relative displacements in the indicator are shown in the following Table.

Relative Displacements, Emergency-Rod Position-Indicator Components in the Indicating Unit

Shaft	Revolutions per Revolution of Centimeter Dial	Revolutions Per in. of Rod Travel	Revolutions Per cm. of Rod Travel	Revolutions For Full Rod Travel (25')
Centimeter Dial	- -	0.254	0.100	76.2
Meter Dial	0.0125	0.00318	0.00125	0.952
Servo-Motor	3.00	0.762	0.300	228.6
Control-transformer	0.20	0.0508	0.0200	15.24

A push-button-operated slewing switch, below the dials, provides manual synchronization in case the rod has been moved with the indicator de-energized. Access to this switch is obtained by opening the front door of the indicator panel.

The amplifier has five stages of amplification and a self-contained power supply. Two manual adjustments are provided, one to set the gain of the amplifier, the other to balance electrical interference of power frequency.

Operation of the system is similar to that described for the regulating-rod position indicator. The principal difference is in the

use of the slewing switch, instead of the coarse synchro, for synchronization in case the error exceeds the range of the synchros. Synchronization by means of the slewing switch is not necessary under any normal operating conditions or after an emergency shutdown. It is only needed when the rod has been moved with power off the indicator. Depression of the slewing switch substitutes for the error voltage from the control-transformer a 3.2 volt, 60-cycle-per-second signal from half the filament winding of the power transformer. Through the amplifier, this signal drives the servo-motor at full speed until the switch is released. Release of the switch when the dial is near the proper position allows the synchro system to assume control, and normal operation is resumed.

6. Emergency-Rod Position Indicators - Component Description

6a. Instrument Pinion and Support - The instrument pinion and support assembly is shown pictorially in Figure 3.2, page 3.7. The construction is similar to that of the regulating-rod instrument pinion except that less severe tolerances are used in pinion and bearing design.

A disassembled view of the pinion-and-support assembly is given in Figure 3.26.

6b. Rod-Position Transmitter - The emergency-rod position transmitter contains elements of the coarse rod-position indicator, the rod-position recorder, as well as the emergency-rod position indicator. This transmitter is shown pictorially in Figure 3.11. Gearing and instrument arrangement and interior wiring are shown schematically in Figure 3.12. A disassembled view with parts identification is given by Figure 3.29.

The gearing is composed of commercial precision spur gears manufactured by the Reeves Instrument Company. A spring-type anti-backlash

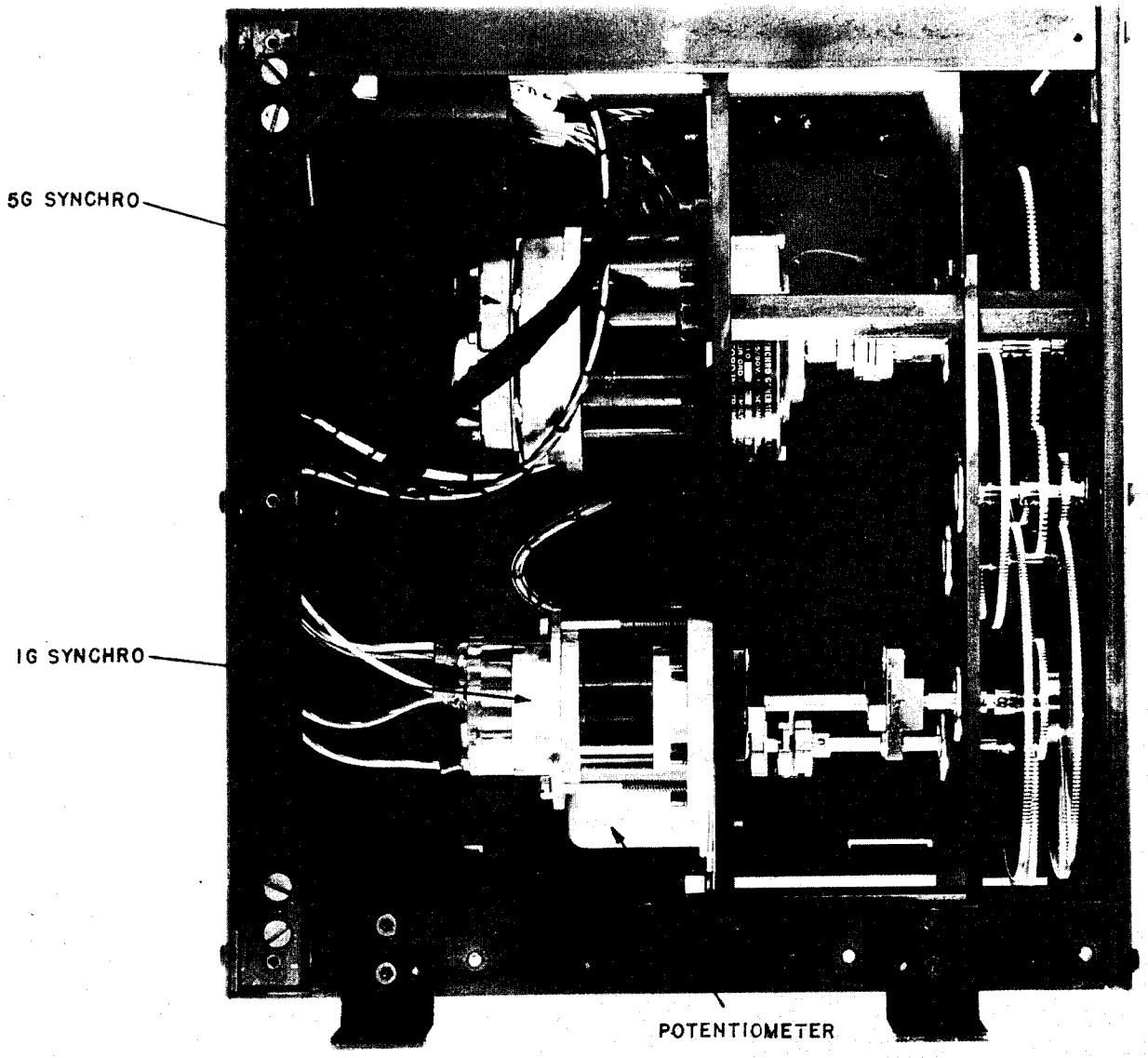
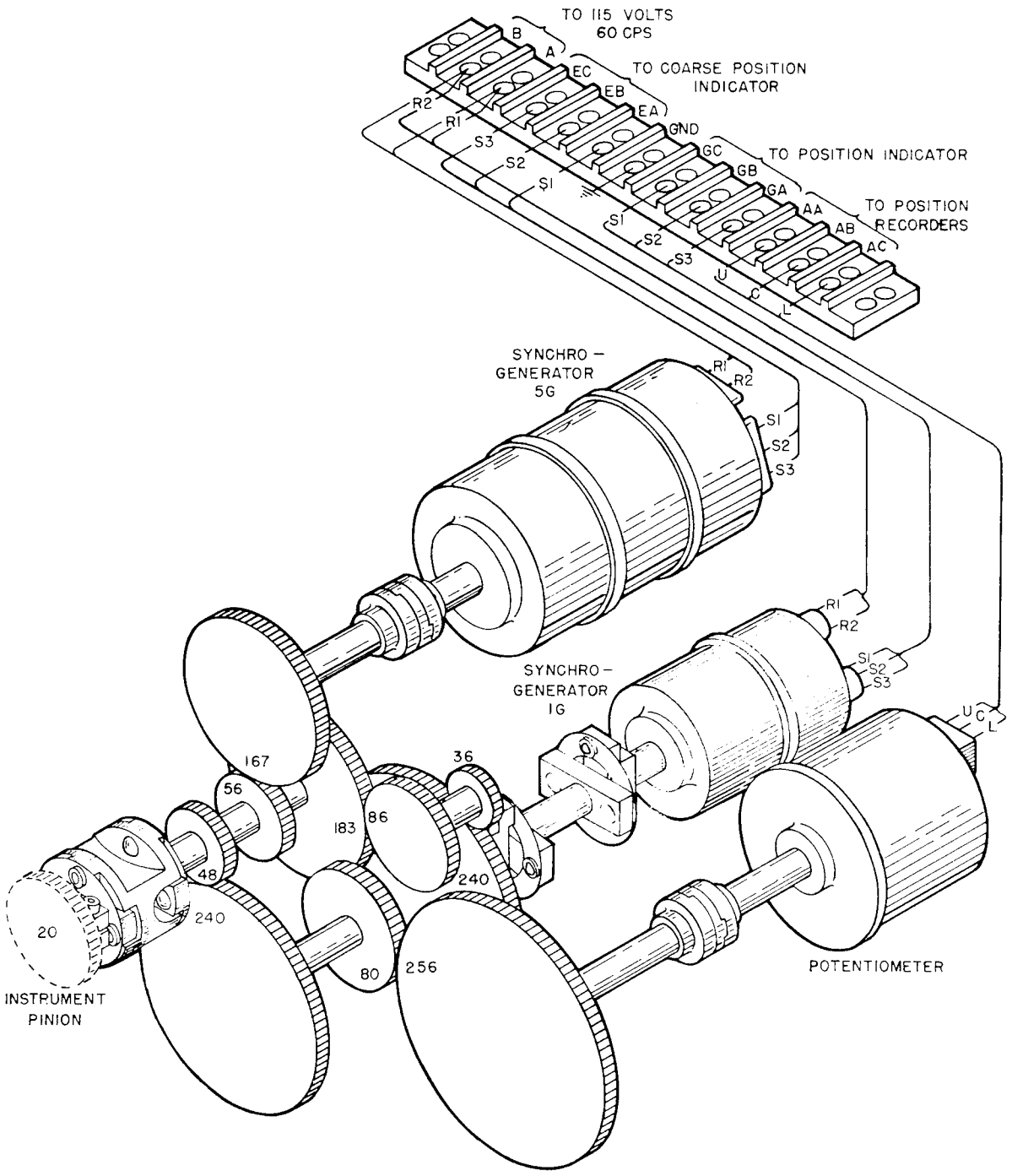


FIGURE 3.11 EMERGENCY-ROD POSITION TRANSMITTER



NOTE: NUMBERS ON GEARS DESIGNATE
NUMBER OF TEETH

FIGURE 3.12 EMERGENCY–ROD POSITION TRANSMITTER

coupling connects the synchro-generator to the gearing.

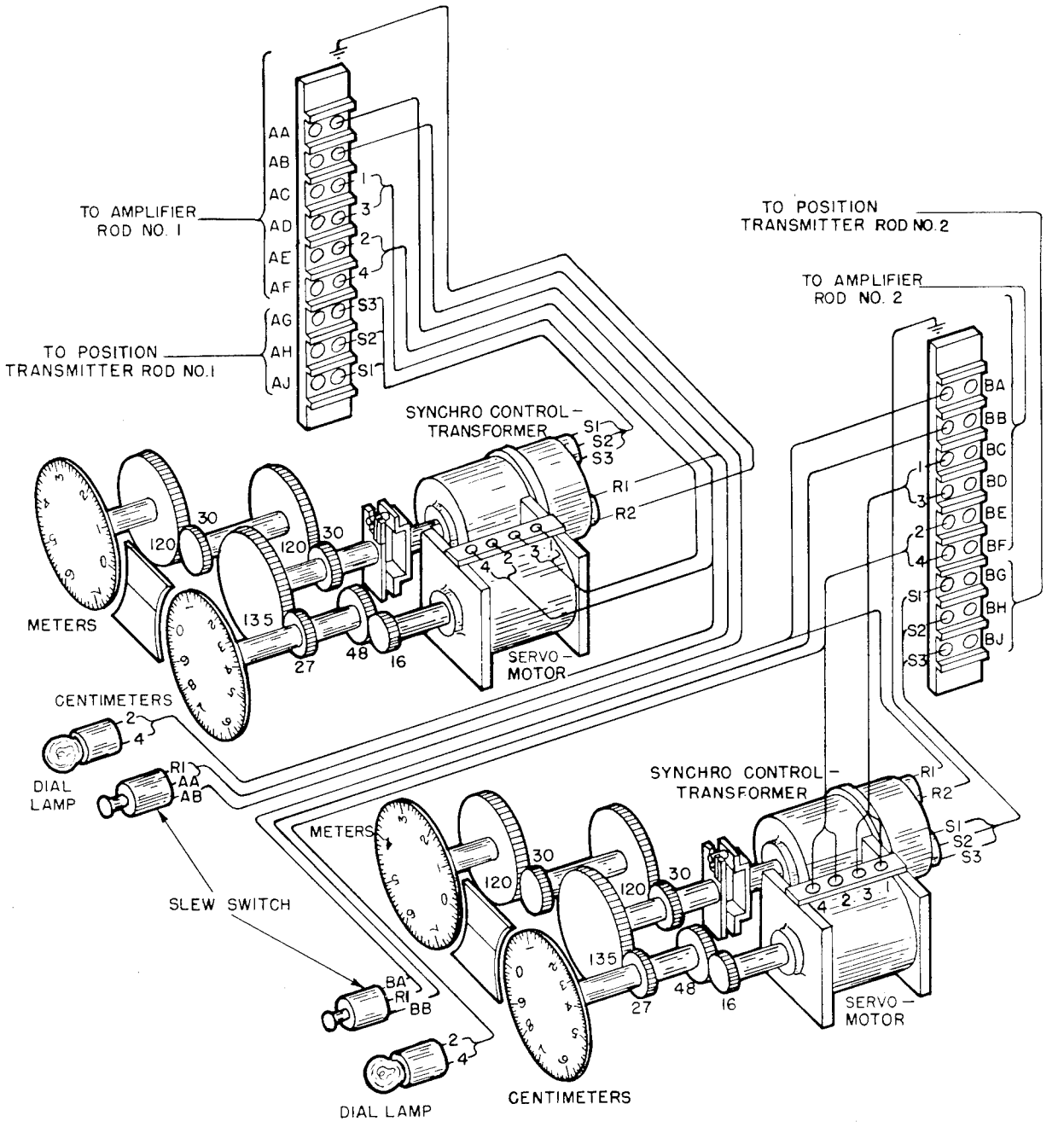
6c. Position-Indicating Units - Each position-indicating unit consists of a servo-motor (Diehl, Type FPE 25-11), a synchro control-transformer (U. S. Navy, Mark 5, Size 1CT), a gear train, and an indicating dial assembly. Typical internal wiring and the mechanical arrangement of the indicators are shown for Rods one and two in Figure 3.13. Front and back views of another typical pair - that for Rods three and four - are shown in Figures 3.14 and 3.15, respectively. A disassembled view of the unit for Rods five and eight is given in Figure 3.30. All pictures apply equally to any pair, except for the terminal markings and the slewing-switch nameplates. Terminal markings for the different indicators differ only in the first letter, as shown below, the second letter for similar terminals being the same for all cases.

First Letter of Terminal Markings

Unit for Rod No.	1	2	3	4	5	6	7
Letter	A	B	C	D	E	F	G
Unit for Rod No.	8	10	11	12	13	14	16
Letter	H	J	K	L	M	N	P

The control-transformer is flange mounted to facilitate zeroing, and is connected to its gear shaft by a spring-type anti-backlash coupling for easy removal and replacement.

All gears are precision spur gears, manufactured by the Reeves Instrument Company. At assembly, the gear hubs are secured to their shafts by setscrews, but after the dials have been synchronized, are permanently fastened by taper pins. Numbers of teeth on gears appear in Figure 3.13. All shafts are mounted in ball bearings in the mechanism housing.



NOTE: NUMBERS ON GEARS DESIGNATE NUMBER OF TEETH

FIGURE 3.13 EMERGENCY-ROD POSITION INDICATING UNIT – RODS NO. 1 AND NO.2

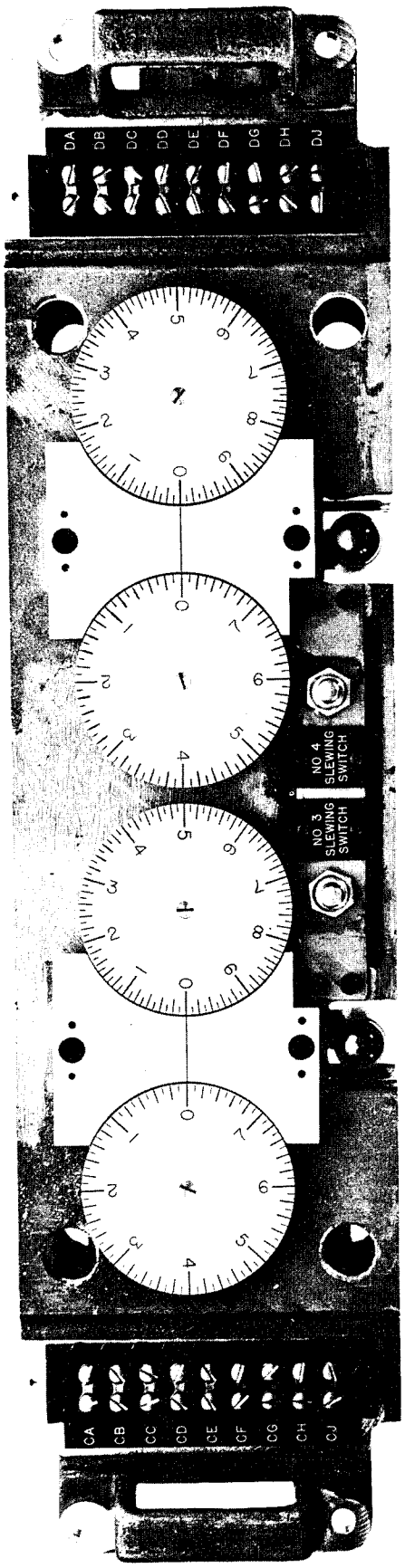


FIGURE 3.14 EMERGENCY-ROD POSITION INDICATING UNIT - RODS NO. 3 AND NO. 4 - FRONT

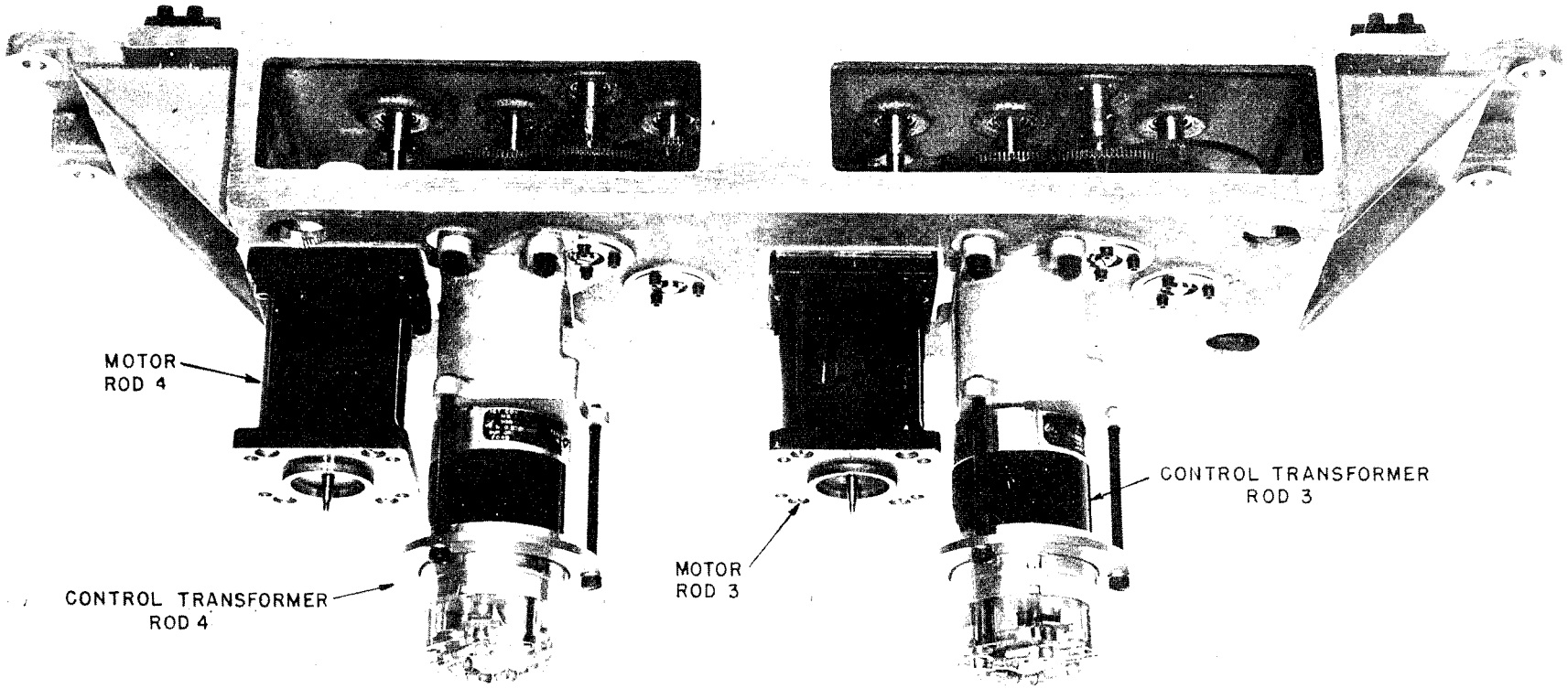


FIGURE 3.15 EMERGENCY-ROD POSITION INDICATING UNIT - RODS NO. 3 AND NO. 4 - REAR

6d. The amplifiers for the emergency-rod position indicators are located in Cabinets TB138-1 and TB138-2 in the equipment room. They are identical with the corresponding equipment for the regulating-rod position indicators except that they do not have switching circuits. A single unit containing amplifier with power supply is illustrated in Figure 3.16. The circuit is shown in Figure 3.17.

7. Emergency-Rod Position Indicators - Adjustment

The procedure for adjustment of the indicator is as follows:

7a. Disconnect one side of each motor field and one side of the control-transformer at the amplifier terminal block. Short the input test points.

7b. Adjust the balance control for a minimum voltage at the output test terminals. Tighten the locking nut while the meter is attached.

7c. Remove the short from the input test points.

7d. Apply 1 volt, 60 cycles per second to the input terminals and adjust the gain control to produce 60 volts at the output test terminals.

7e. Reconnect the motor fields and control-transformers.

7f. Set the control rod at any known position.

7g. Press the slewing push button until the indicator gives an approximate reading of rod position. Release slewing push button.

7h. Rotate the stator of the control-transformer until the dials indicate the known rod position.

These are the general steps required to synchronize the unit.

8. Coarse Rod-Position Indicators

The coarse rod-position indicators are intended to give approximate, easily read information on all rod positions. The rod position is

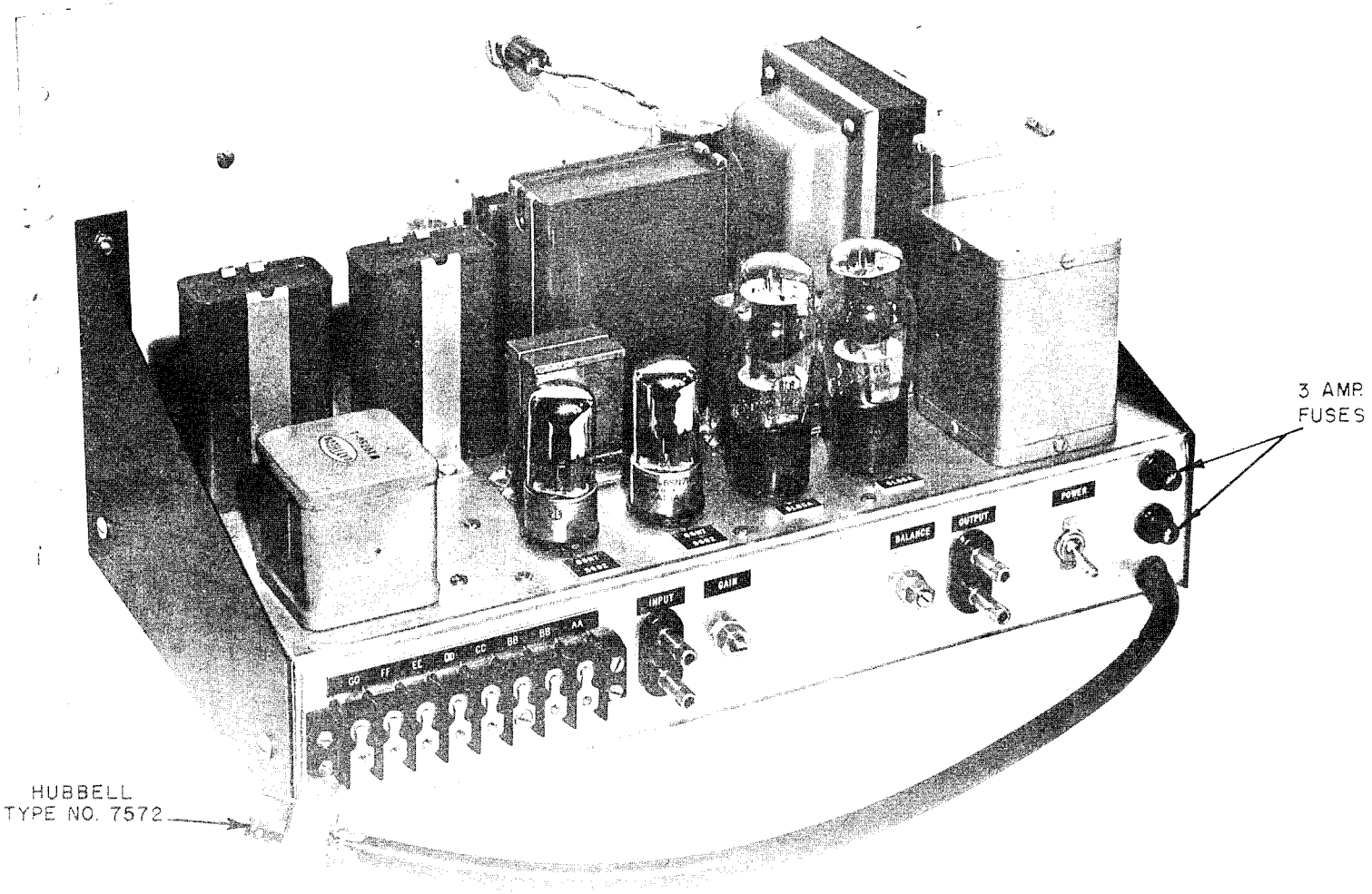
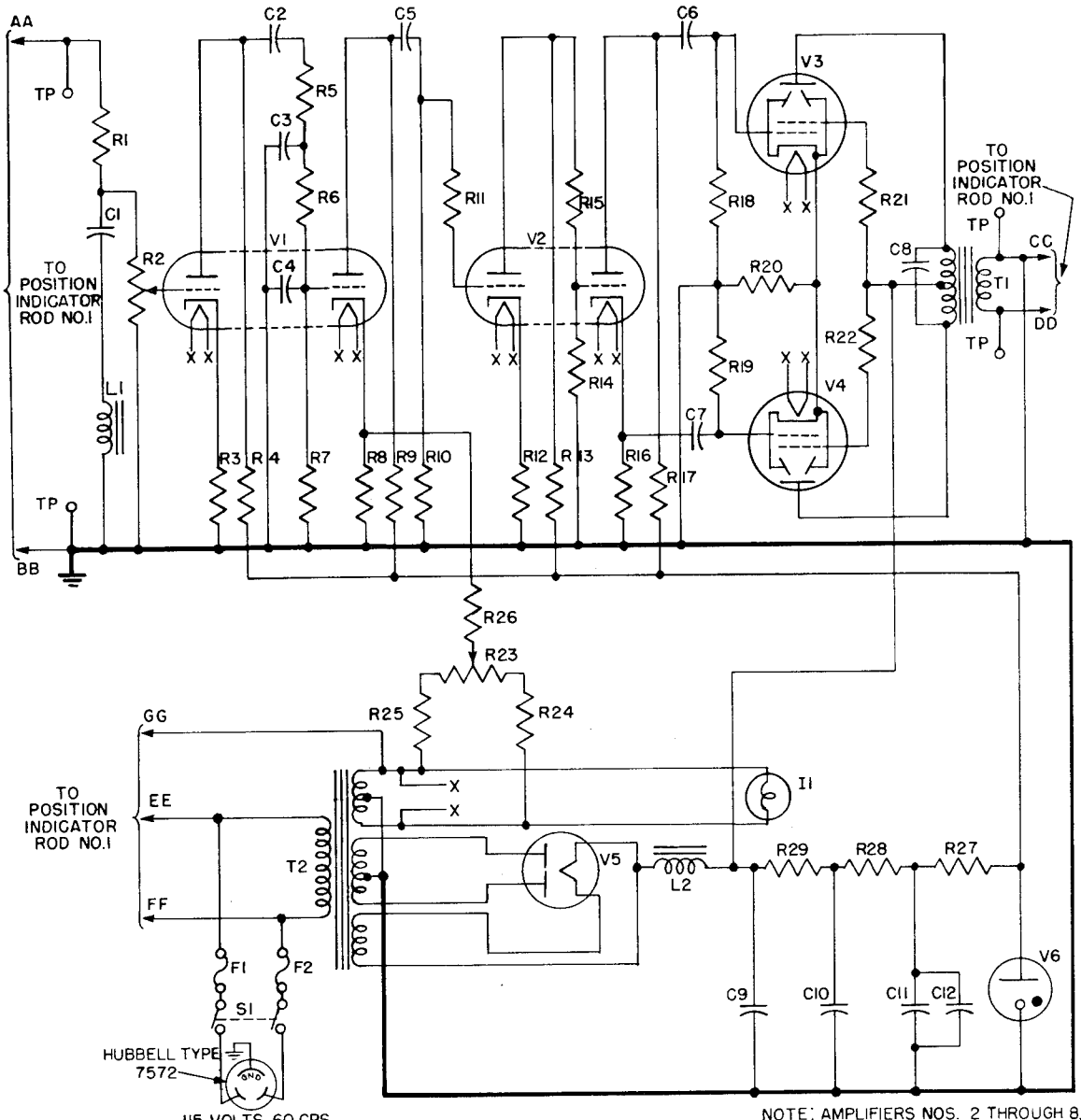


FIGURE 3.16 AMPLIFIER FOR EMERGENCY-ROD POSITION INDICATOR



NOTE: AMPLIFIERS NOS. 2 THROUGH 8, 10 THROUGH 14 AND 16 IDENTICAL

R1-RESISTOR, 47,000 OHM, ±5%, 1 WATT
R2-POTENTIOMETER, 500,000 OHM, ±10%, 1WATT
R3, R8, R12, R24, R25-RESISTOR, 4700 OHM, ±5%, 1 WATT
R4, R9, R13-RESISTOR, 100,000 OHM, ±5%, 1WATT
R5, R6-RESISTOR, 33,000 OHM, ±5%, 1 WATT
R7, R10, R11-RESISTOR, 470,000 OHM, ±5%, 1 WATT
R14, R15-RESISTOR, 1MEGOHM, ±5%, 1WATT
R16, R17-RESISTOR, 27,000 OHM, ±5%, 1 WATT
R18, R19-RESISTOR, 220,000 OHM, ±5%, 1 WATT
R20-RESISTOR, 100 OHM, ±5%, 5 WATTS
R21, R22-RESISTOR, 100 OHM, ±5%, 1 WATT
R23-POTENTIOMETER, 600 OHM, ±10%, 1WATT
R26-RESISTOR, 10,000 OHM, ±5%, 1WATT
R27-RESISTOR, 1000 OHM, ±5%, 5 WATTS
R28, R29-RESISTOR, 2500 OHM, ±5%, 5 WATTS
C1-THREE CAPACITORS: TWO SMALL MOLDED PAPER AND ONE .05MFD CAN TYPE (AEROVOX TYPE 416B) SELECTED TO RESONATE WITH CHOKE L1 AT 1.25 VOLTS 60 CPS (REQUIRED CAPACITY APPROX. 0.1MFD

C2, C5, C6, C7-CAPACITOR, 1MFD, ±10%, AEROVOX TYPE 418 CB
C3, C4,-CAPACITOR, DUAL TYPE 0.1-0.1 MFD C.D. TYPE DYR6011
C8-CAPACITOR, 0.25MFD, ±10%, C.D. TYPE DYR6025
C9-CAPACITOR, 10MFD, ±10%, AEROVOX TYPE 609
C10, C11-CAPACITOR, 4MFD, ±10%, AEROVOX TYPE 609
C12-CAPACITOR, 6 MFD, ±10%, C.D. TYPE TJ6060G
L1-INDUCTOR, RAYTHEON TYPE M-10750-1
L2-INDUCTOR, THORDARSON TYPE T-20C54
T1-TRANSFORMER, RAYTHEON TYPE M-11645-1
T2-TRANSFORMER, THORDARSON TYPE T-22R33
V1, V2-VACUUM TUBE, TYPE 6SN7 OR TYPE 5692
V3, V4-VACUUM TUBE, TYPE 6L6GA
V5-VACUUM TUBE, TYPE 5U4G
V6-VOLTAGE REGULATOR TUBE, VR-150 (OD3)
I1-PILOT LAMP, GE #47
S1-SWITCH, CUTLER-HAMMER TYPE 7360K8
F1, F2-FUSE BUS, 3AG, 3 AMP

FIGURE 3.17 AMPLIFIER FOR EMERGENCY-ROD POSITION INDICATOR - ROD NO. 1

presented as a horizontal column of light whose length varies from zero to ten inches as the rod moves into the reactor. The precision of the reading is better than 1.0 per cent of full scale.

There are 16 coarse rod-position indicators, one for each of the control rods. Each indicator consists of the following components:

An instrument pinion for sensing rod position through the rack attached to the rod.

A rod-position transmitter, located on the rod structure, containing a synchro-generator and necessary gearing.

An indicating assembly consisting of a synchro-motor, gearing, a lead screw with travelling nut, a light baffle, a light trough, and a light source in the indicator cabinet. The indicator assembly also contains two limit lights for each rod.

Two limit-light switches on the control-rod support structure.

The arrangement of the indicating systems for Rods 9 and 11 is shown schematically in Figure 3.18. These two systems typify the arrangement for the regulating rods and for the emergency rods, respectively. The two gear trains in the transmitters have the same overall gear ratios, the variation in the arrangement being due to the differences in the drives to the position indicating components. Gear ratios and shaft revolutions for both transmitters are shown in the following table.

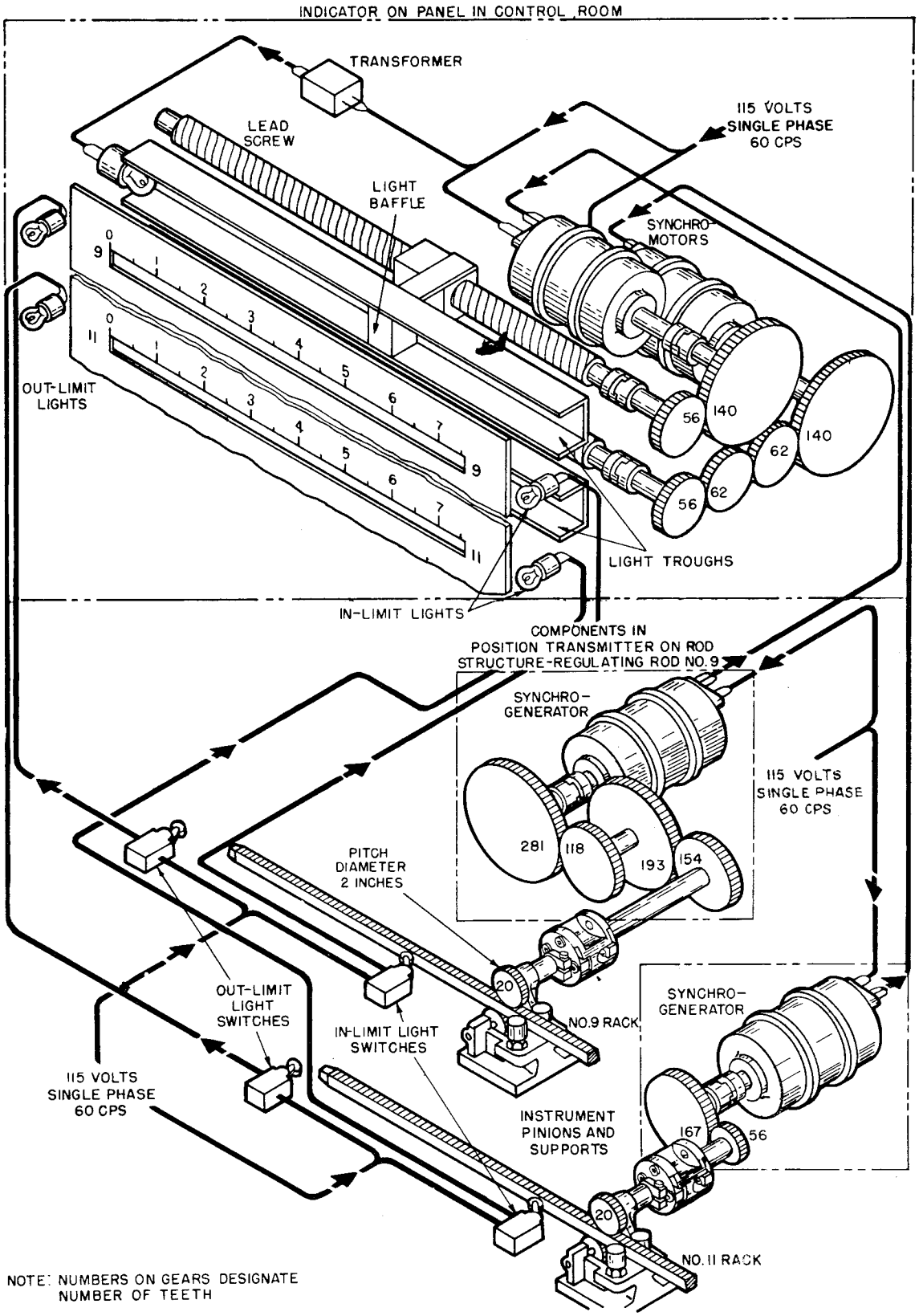


FIGURE 3.18 COARSE ROD-POSITION INDICATOR

Gear Ratios and Shaft Revolutions
Coarse Rod-Position Indicator Components
in the Transmitter

Shaft	Revolutions per Revolution of Instrument Pinion	Revolutions Per meter of Rod Travel	Revolutions For Full Rod Travel (25')
Instrument Pinion	- - -	6.27	47.77
Synchro-generator	0.335	2.10	16.00

The 16 indicating assemblies are mounted, eight in each of two indicator cabinets, the two cabinets being located side by side at the right end of the control panel. As shown in Figure 3.18, each cabinet has eight linear scales arranged one above the other. Each scale is graduated in meters of rod insertion over a range of 7.62 meters in a scale length of 12 inches. Below each scale is a slot 0.25 inch wide. A green glass plate over the front of the light troughs is visible through the slots, and is illuminated by reflection from the troughs. Light baffles are moved in the troughs by lead screws so that displacement from the left end of the scale is proportional to rod insertion in the reactor. Thus, the length of the illuminated portion of the slot, as read on the scale, represents rod insertion. A number opposite each scale identifies the rod to which the indicator applies.

The system operates directly on the signal transmitted from the synchro-generator to the synchro-motor. No power amplification is used.

The limit-light switches are operated by contact of the end of the rack with the switch actuating arm. The "out" switch is normally

open and is closed when the rack end strikes the actuating arm. The actuating arm of the "in" switch rides on the side of the rack, holding the switch open. When the end of the rack clears the switch arm, the switch is closed by its spring.

9. Coarse Rod-position Indicators - Component Description

9a. Instrument Pinion and Support - The instrument pinions which provide rack position pickoff for the regulating- and emergency-rod position indicators also serve the same purpose for the coarse rod-position indicators.

9b. Rod-Position Transmitter - The transmitting elements are housed along with the elements for all of the other rod-position transmitting elements for a given rod. The electrical element of this system is a size 5G, U. S. Navy type, Mark 5, synchro-generator. Connection between synchro and gearing is by means of a precision Oldham-type coupling.

9c. Position-indicating Units - Arrangement of mechanical and electrical elements and wiring of a group of eight indicators is shown in Figure 3.19.

Indicator assembly M5,[1] on section two of Control Panel M, has eight individual indicators to show the insertion of rods numbered 1 to 8, inclusive, and eight pairs of limit lights to warn the operator when the corresponding rod or rods approach the selected limit of travel, in or out. Indicator M2 on section one, functions similarly for rods numbered 9 to 16, inclusive. The two instruments are identical except for rod identification numbers and terminal markings. A front view of

---

[1] Instrument numbers appearing in the text refer to an instrument list issued separately.

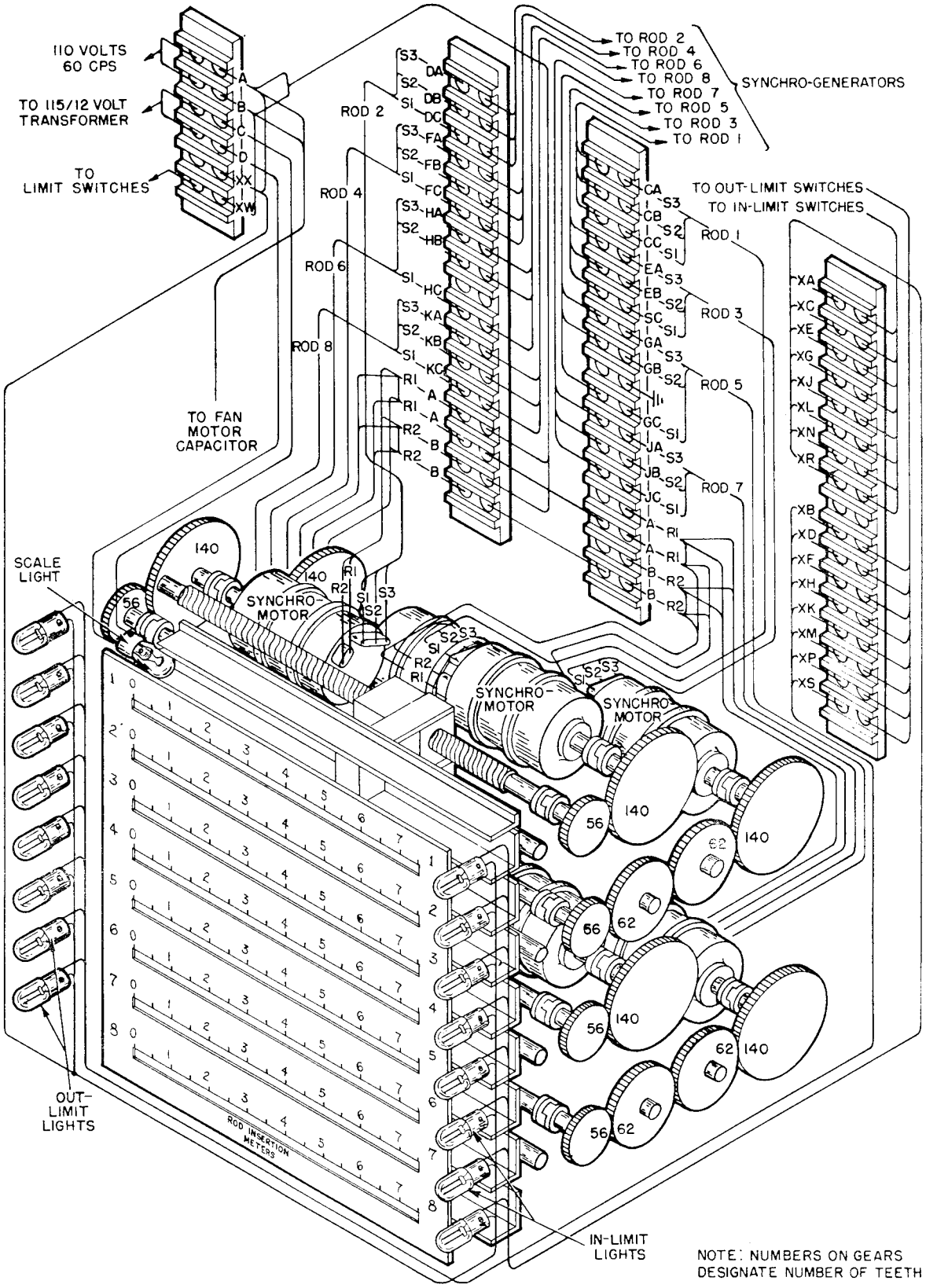


FIGURE 3.19 COARSE ROD-POSITION INDICATOR

one indicator is shown in Figure 3.20.

Each indicator consists of a supporting frame, a front cover, an indicator plate, a baffle-drive assembly with light reflectors and lights, eight synchro-motors, eight gear trains, and a ventilating fan. A top view is shown in Figure 3.21.

The supporting frame, an assembly of steel plates and angles bolted to Control Panel M, provides support and enclosure for the components of the instrument.

The front cover is a steel plate weldment, hinged to the support structure and secured by two knurled-head screws. A large rectangular cutout in the door permits a view of the indicator plate. At each side of the cutout is a vertical row of eight red limit lamps with a rod number beside each lamp. The left-hand row is labeled OUT LIMIT and the lighting of any lamp in this row indicates that the corresponding rod is approaching the selected limit for outward travel. The right-hand row is labeled IN LIMIT and its lights similarly indicate approach to the inward limit.

The indicator plate is a steel plate hinged to the structure and secured by thumb latches. Eight horizontal scales are engraved on the plate, each having numbered graduations, 0 to 7, representing rod insertion in meters, and intermediate unnumbered graduations representing decimeters. Below each scale is a horizontal slot extending over the full scale length. Behind each slot is a green glass plate, and behind that an opal glass plate, both secured to the indicator plate.

Immediately behind the indicator plate are eight horizontal light troughs formed by polished chrome-plated angles. A white lamp

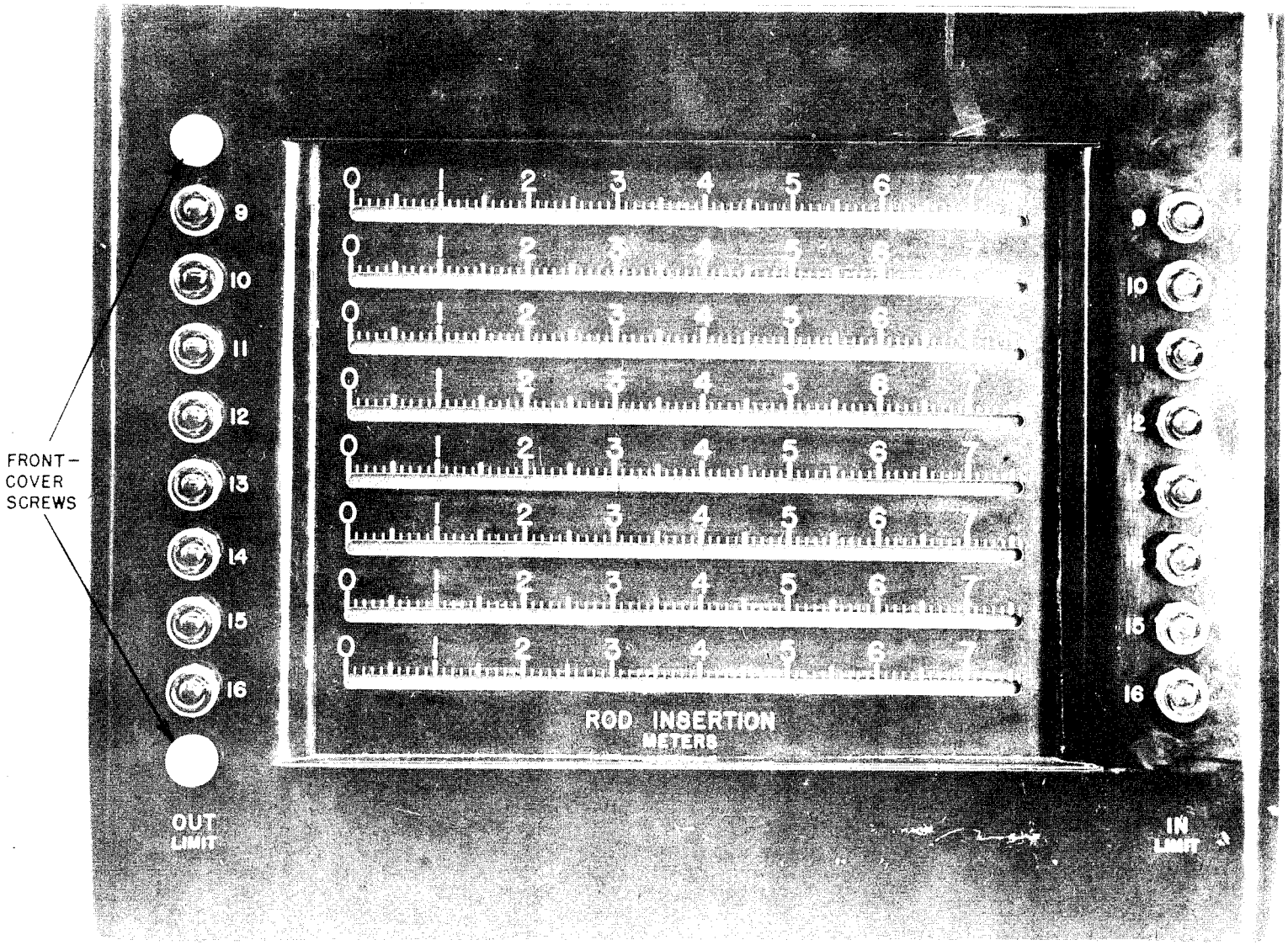


FIGURE 3.20 COARSE ROD-POSITION INDICATOR - FRONT

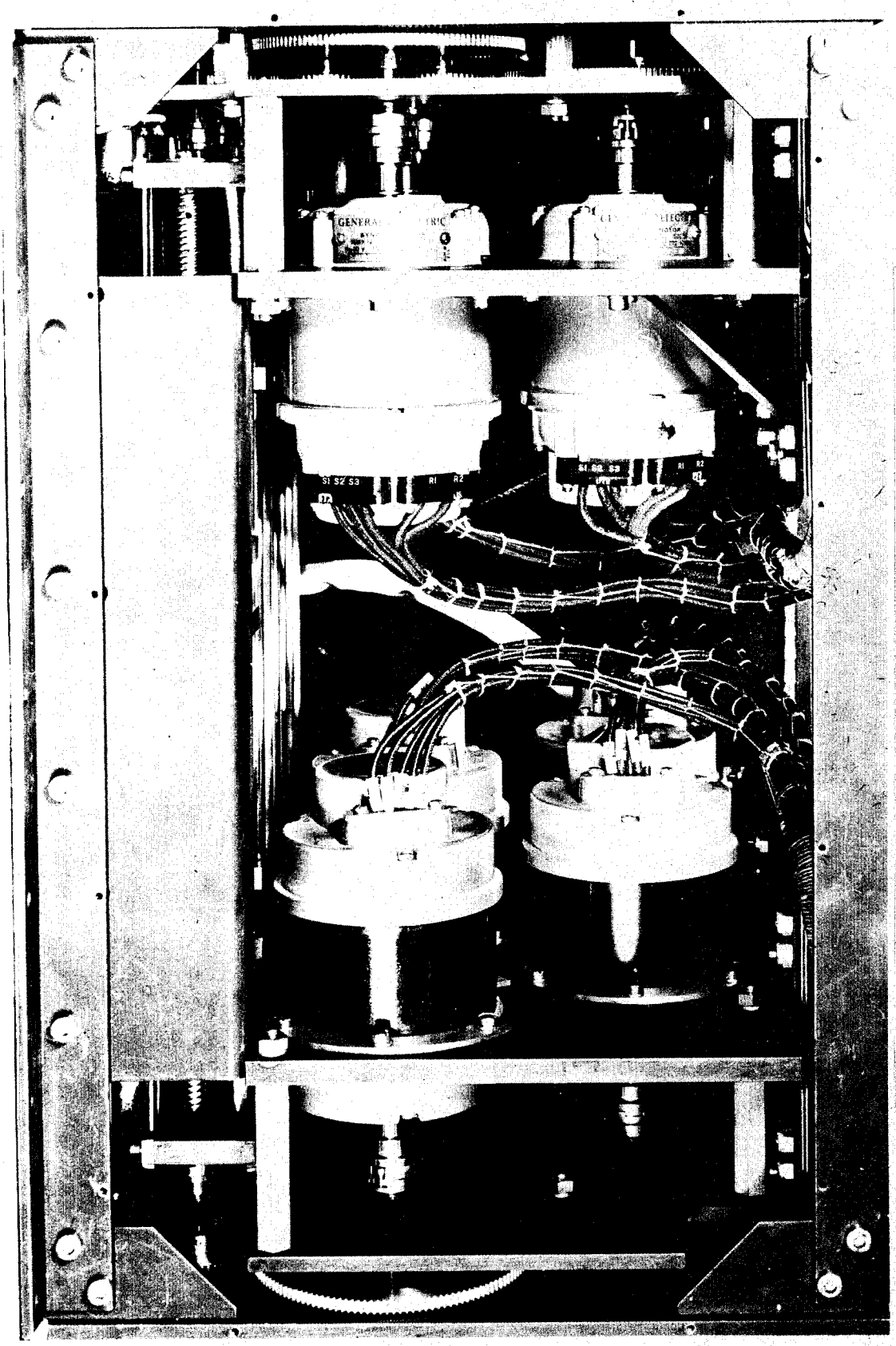


FIGURE 3.21 COARSE ROD-POSITION INDICATOR - TOP COVER OFF

at the left end of each trough supplies illumination which is reflected onto the opal glass by the polished surface.

In each trough is a baffle assembly consisting of a baffle and a mirror secured to a small plate weldment. The baffle is made of shim stock bent to form a four-sided wiper that bears against the three sides of the trough and the opal glass plate, to prevent illumination of that part of the glass at the right of the baffle. The mirror faces toward the left to increase the illumination on that side of the baffle. A view of trough-and-baffle assembly is shown in Figure 3.22. The weldment extends back through a slot in the trough, where it is secured to a block that slides on a horizontal rod. This arrangement is illustrated in Figure 3.23. A horizontal lead screw is threaded into this block and is driven by one of the synchro motors through a gear train.

The 5F, Navy-type synchro-motors are arranged in two groups of four each, one group on each side of the instrument, as shown in Figure 3.24. Each is flange mounted on a vertical support plate to permit zeroing. Motor shafts are connected to their gear shafts by Oldham-type couplings to facilitate removal and replacement. One pair of each group is directly behind the lead screws and the other pair is further back, staggered vertically with respect to the first pair.

The gear trains are arranged as indicated in Figure 3.19. All gears are precision spur gears manufactured by the Reeves Instrument Company. Each train from the synchros nearest the front has one gear coupled to the synchro shaft and a second coupled to the lead screw. Those for the rear synchros are similar except for the addition of two idler gears to accommodate the increased center distances. All gear shafts turn in ball bearings.

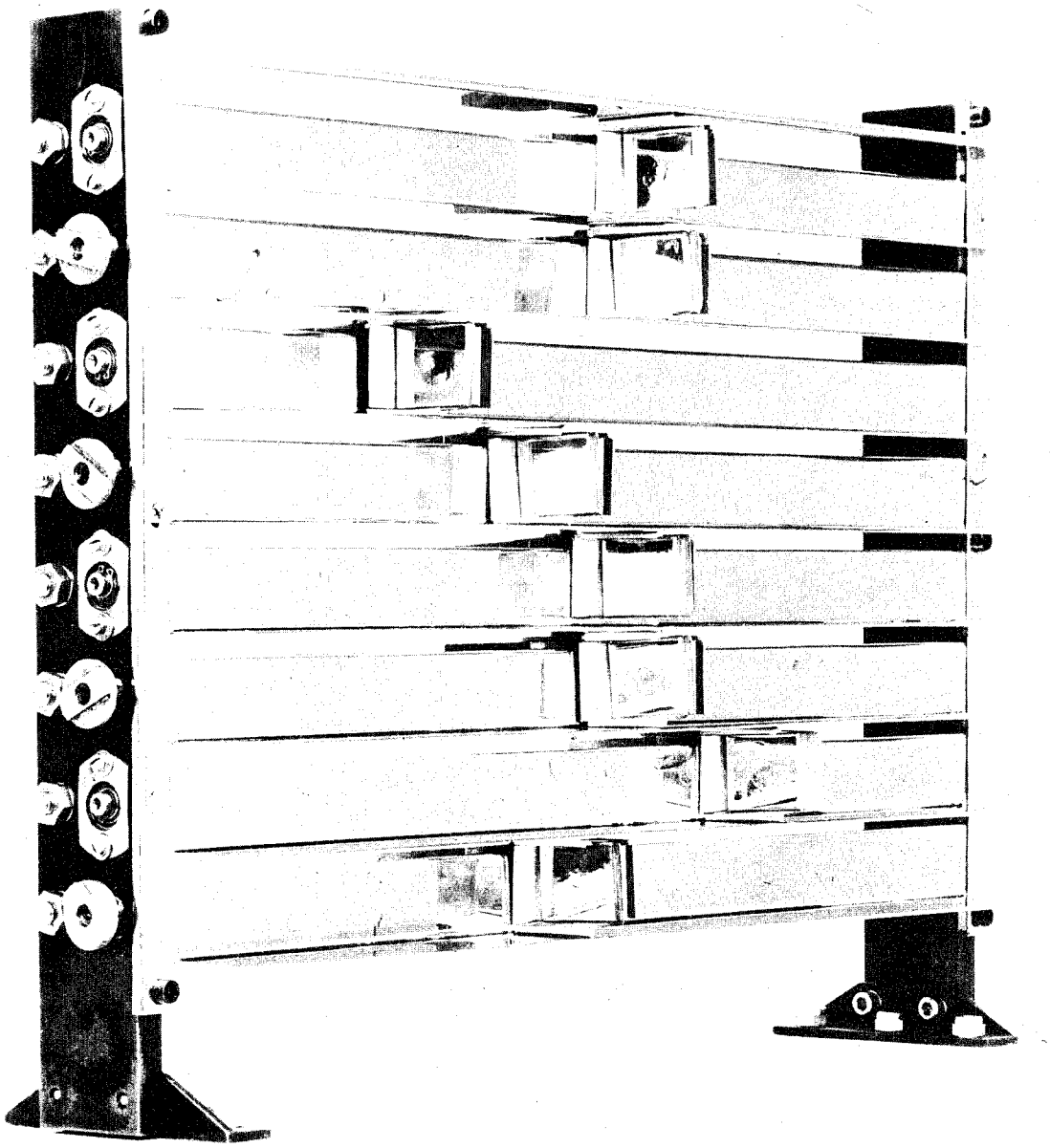


FIGURE 3.22 LIGHT BAFFLES FOR COARSE ROD-POSITION INDICATOR

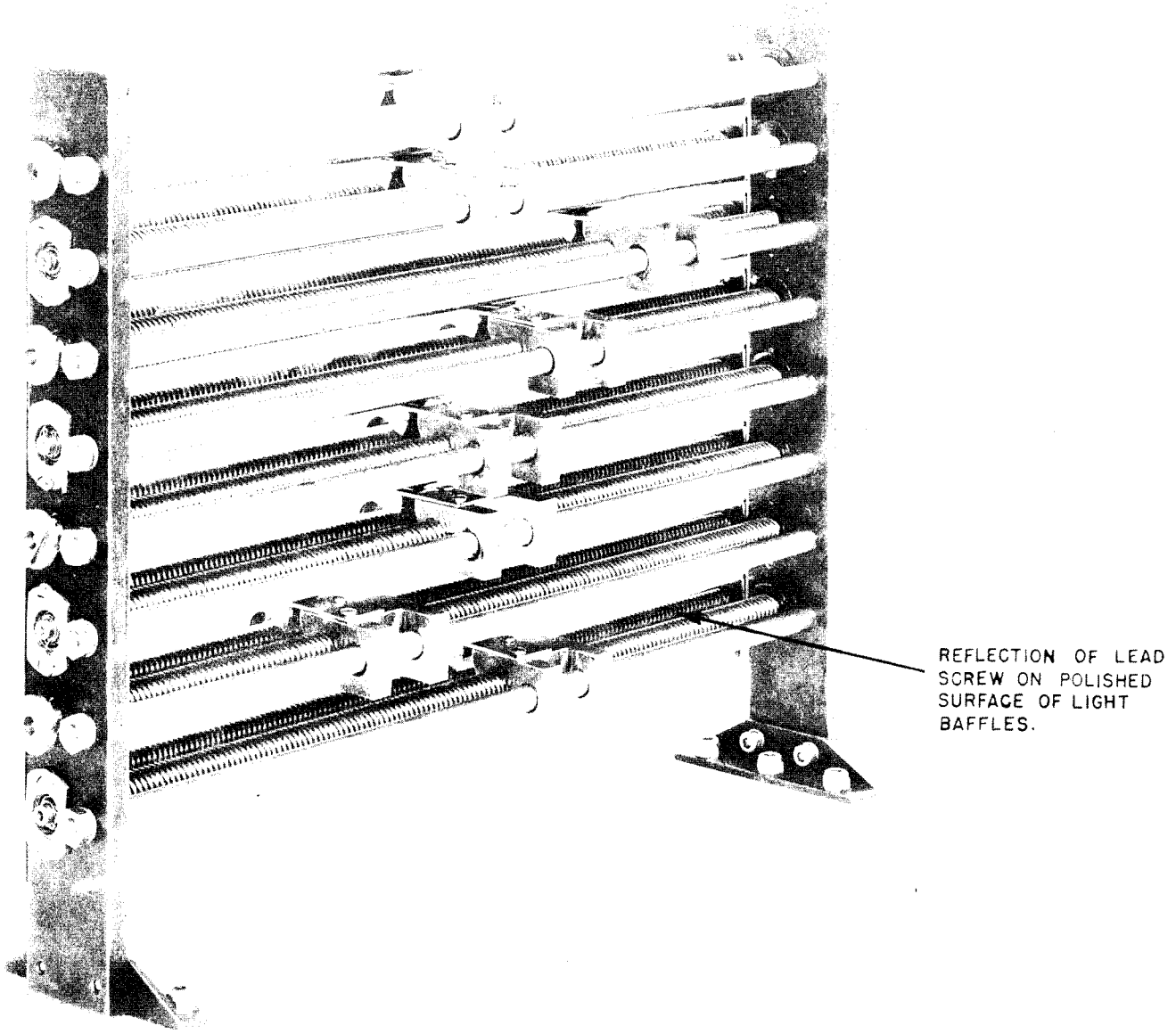


FIGURE 3.23 LEAD SCREWS FOR COARSE ROD-POSITION INDICATOR

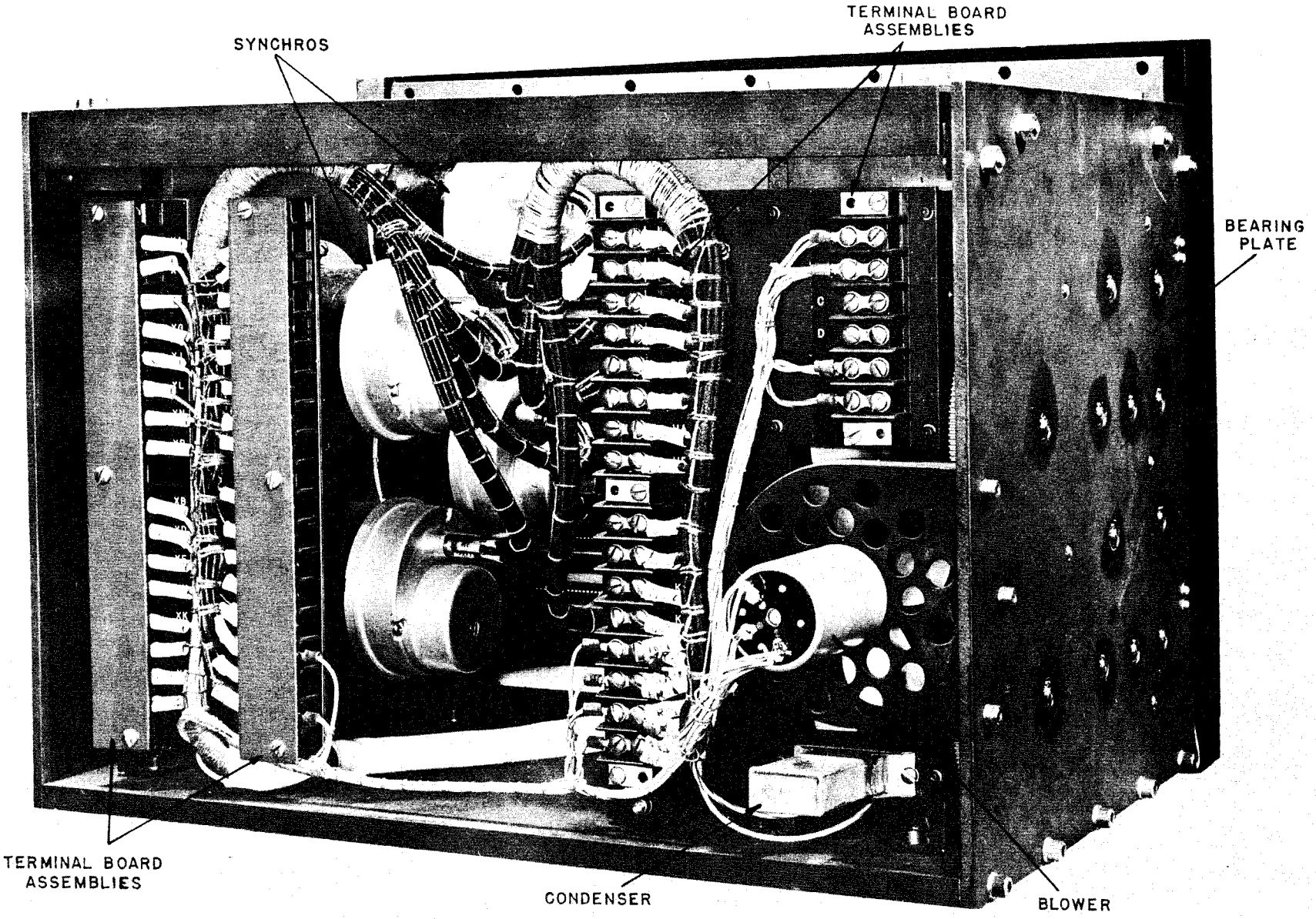


FIGURE 3.24 COARSE ROD-POSITION INDICATOR - REAR

The ventilating fan is motor driven and is intended to provide cooling air if excessive heat is developed by the scale illuminating lamps. It is not expected that the use of the fan will be necessary with the lamps initially furnished.

9d. Limit-light Switches - The limit-light switches are short travel, SNAP LOCK switches, Type 16 D-200-45A2, manufactured by National Acme Company. All of these switches are similar, each having two normally open and two normally closed contacts. The normally open contacts are used in the OUT switches and the normally closed contacts in the IN switches.

The switch mounting bolts fit into slotted holes in the support members so that their positions can be closely adjusted. The switch arms can be moved on their shafts, affording adjustment in the switch arm operating positions.

10. Rod-Position Recorders

Two single-line strip-chart recorders provide continuous records of the position of the two regulating rods. Two eight-point strip-chart recorders provide intermittent records of the position of all 16 rods. The precision of all records should be better than $\pm$ 0.5 per cent of full scale.

As a typical example, the arrangement for Rods 9 and 10 is shown schematically in Figure 3.25.

For each rod the system components involved are:

An instrument pinion for sensing rod position through the rack attached to the rod.

A rod-position transmitter, located on the rod structure, containing a potentiometer and necessary gearing.

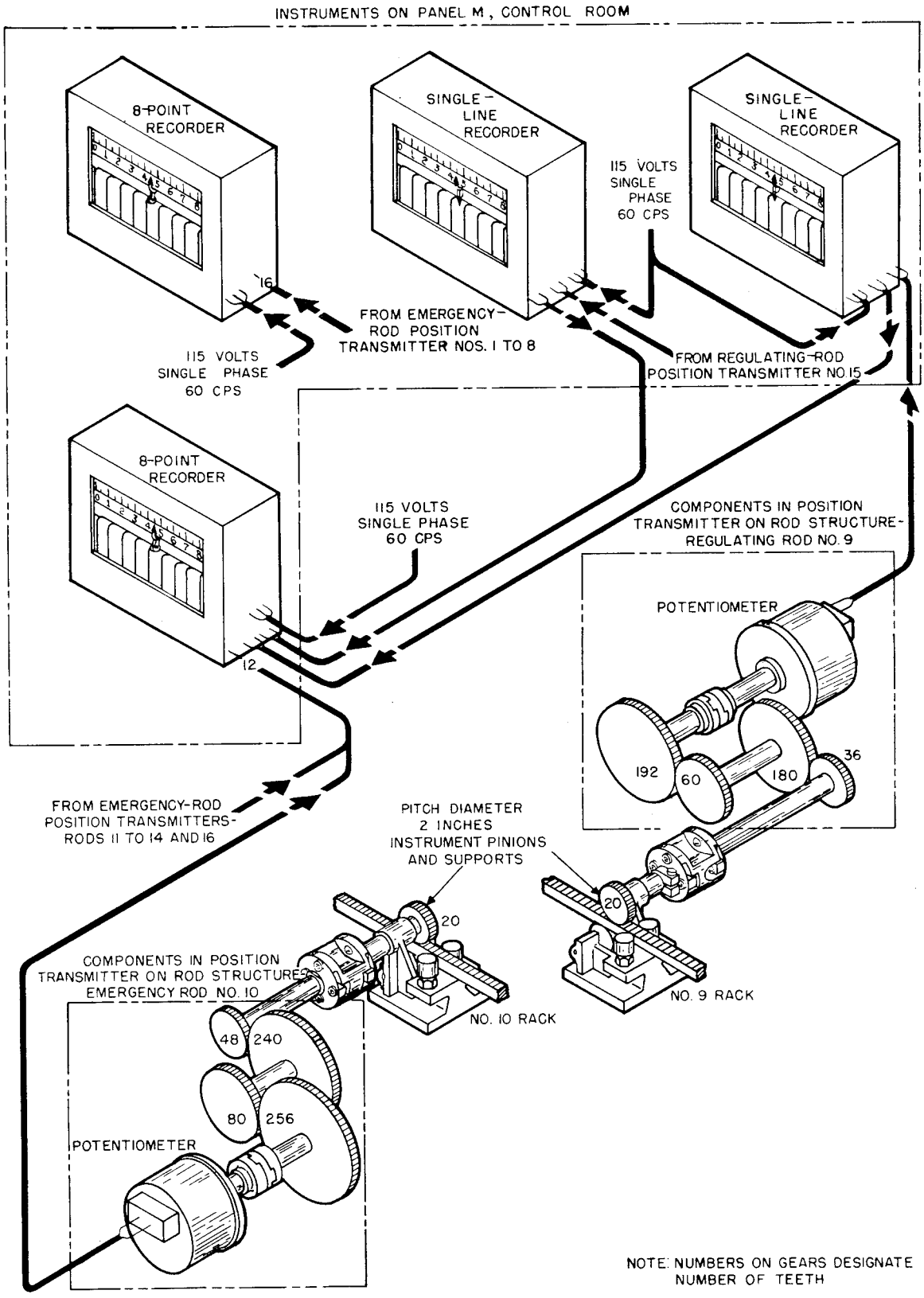


FIGURE 3.25 ROD-POSITION RECORDING SYSTEM

A receiver and recorder consisting of a measuring and amplifying circuit and standard recording instruments.

The potentiometer in an emergency-rod transmitter is driven from the transmitter input shaft through the gear train shown in Figure 3.25. This train has a speed ratio of 16 to 1, giving a potentiometer movement of .392 turns per meter and 2.99 turns for full rod travel (25').

Each recorder is a standard Brown Instrument Company strip-chart instrument having a scale 11 inches long, graduated in meters from 0 to 8 meters. The chart is driven by a synchronous motor at a speed of 2 inches per hour. Spare change gears are furnished to provide alternate speeds of 4, 6, or 8 inches per hour.

A commutator, driven in synchronism with the chart, connects the potentiometer in sequence with the eight transmitting potentiometers at intervals of 15 seconds. Multicolored impressions are used to assist in rod identification.

The transmitter components for the regulating rods are similar to those for the emergency rods, except for variations in the gear train. These variations do not change the overall gear ratio.

Each of the regulating rods has a single-record continuous type Brown Instrument Company recorder. The chart, chart drive, and scale are similar to the corresponding components of the eight-point recorders described above. No selecting commutator is necessary. In addition, each recorder has a re-transmitting potentiometer, which relays the rod-position data to an eight-point recorder.

11. Parts List - Instrument Pinion Support Assembly 6546DN048 (For Regulating Rods)

Reference Figure 3.26	Name of Part	Part Number	Number Required
	Instrument Pinion Assembly	6546DN017	1
14 thru 19	Bottom Roller Assembly	6546BN026	1
7 or 8 thru 12	Side Roller Assembly	6546BN008	2
1	Shield	6546AP107	1
4	Spacer No. 1 (outer)	6546AP104	1
2	Spacer No. 1 (inner)	6546AP103	1
13	Bearing cap	6546BP095	2
3	Bearing, Barden Matched pair	202HDB	1
6	Base Casting	6546DP021	1
5	Rack Pinion	6546BP101	1
	Stud	6546AP042	4
	Wedge Plate Weldment	6546FP002	1
	Top Wedge	6546CP004	1
	Bottom Wedge	6546CP005	1
	Bolt	6546AP063	3
	Bolt	6546AP005	3
	Bolt	6546AP006	4

Note: Miscellaneous hardware not listed.

12. Parts List - Instrument Pinion Support Assembly 6546DN047 (For Emergency Rods)

Reference Figure 3.26	Name of Part	Part Number	Number Required
	Instrument Pinion Assembly	6546DN018	1
14 thru 19	Bottom Roller Assembly	6546BN027	1
7 or 8 thru 12	Side Roller Assembly	6546BN008	2
1	Shield	6546AP107	1
4	Spacer No. 1 (outer)	6546AP104	1
2	Spacer No. 1 (inner)	6546AP103	1
13	Bearing Cap	6546BP095	2
3	Bearing, Fafnir matched pair	M7202DB	1
6	Base Casting	6546DP020	1
5	Rack Pinion	6546RP100	1
	Stud	6546AP042	4
	Wedge Plate Weldment	6546EP002	1
	Top Wedge	6546CP004	1
	Bottom Wedge	6546CP005	1
	Bolt	6546AP063	3
	Bolt	6546AP005	3
	Bolt	6546AP006	4

Note: Miscellaneous hardware not listed.

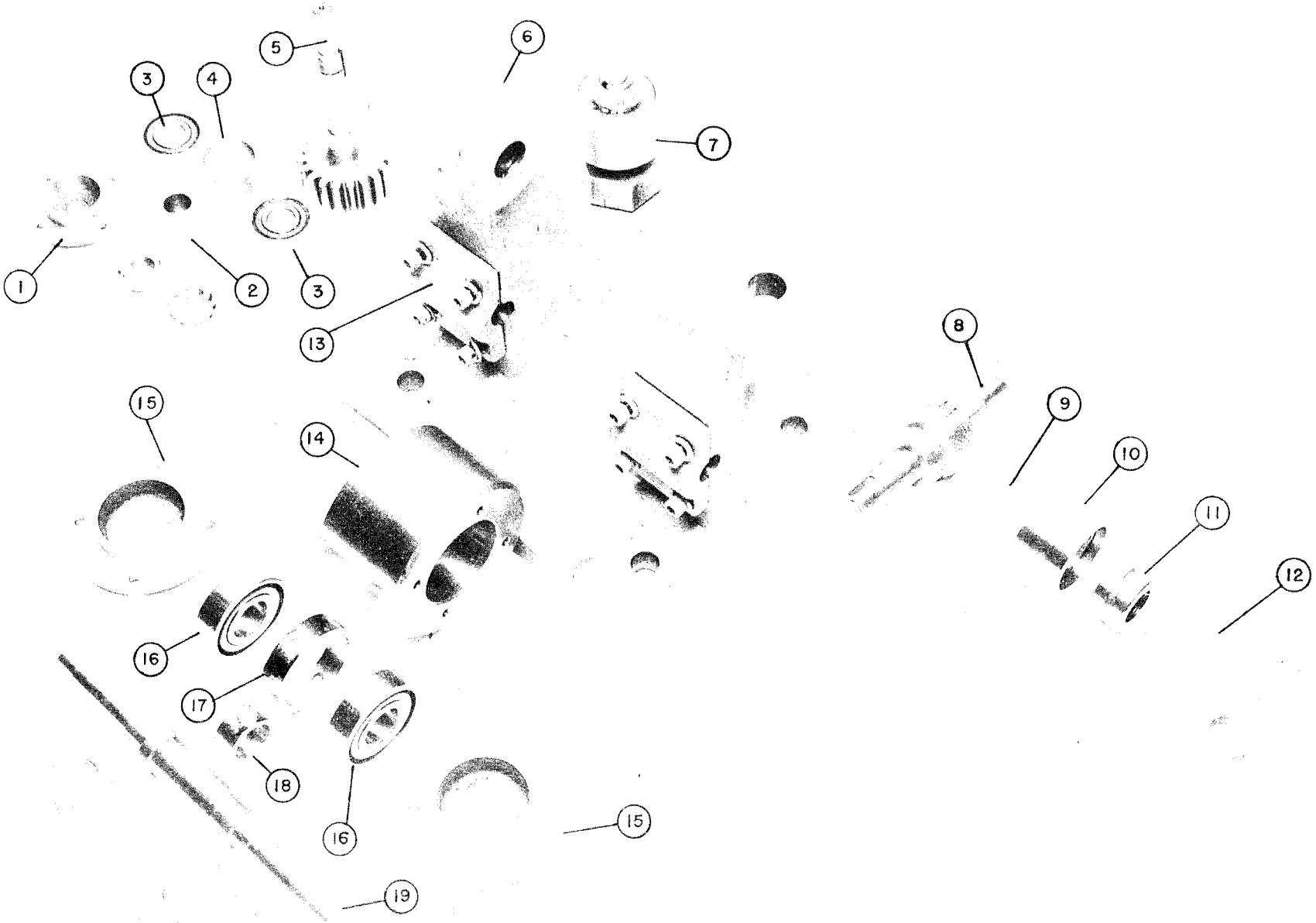


FIGURE 3.26 INSTRUMENT PINION SUPPORT

13. Parts List - Regulating Rod Position Transmitter Assembly 6546EN030

Reference Figure 3.27	Name of Part	Part Number	Number Required
	Synchro, Potentiometer, Helipot Assembly	6546DN038	1
4	Male Coupling Assembly	6546AN033	1
28	Coupling Assembly	6546AN050	1
6	Male Coupling Assembly	6546AN027	1
2	Support Plate	6546DP109	1
12	1G Synchro Clamp	6546BP158	2
5	1G Synchro Generator	Navy Type	2
9	Potentiometer - Brown Inst. Co.	6546AP137	1
13	Synchro Ring	6546AP012	1
14	Mounting Plate	6546AP564	1
3	Beckman Helipot, Helipot Corp.	Model E	1
7	5G Synchro-Generator	Navy Type	1
11	5G Synchro Clamp	6546BP157	2
8	5G Coupling, Reeves Inst. Corp.	A-SP-142	1
10	Male Coupling, Reeves Inst. Corp.	A-SP-111-1	1
	Synchro Housing Altered	6546BP417	1
	Gear Train Assembly	6546DN031	1
30	Gear and Hub Assembly	6546BN033	2
24	Female Coupling Assembly	6546AN028	2
33	Gear and Hub Assembly	6546BN035	1
29	Gear and Hub Assembly	6546BN034	1
26	Gear and Hub Assembly	6546BN038	1
23	Gear and Hub Assembly	6546BN036	1
22	Gear and Hub Assembly	6546BN039	1
19	Gear and Hub Assembly	6546BN037	1
18	Spacer	6546BP170	4
15	Bearing Plate	6546CP063	1
16	Spacer	6546AP249	4
17	Front Plate	6546DP059	1
35	Collar, Reeves Inst. Corp.	A-SP-496	6
32	1G Shaft	6546AP225	1
20	Female Coupling, Reeves Inst. Corp.	A-SP-113-1	2
34	Potentiometer Shaft	6546AP224	1
27	Gear, Reeves Inst. Corp.	B-SP-648-36	2
31	Idler Shaft	6546AP223	1
	Instrument Pinion Shaft	6546AP254	1
36	Bearing, New Departure	R-4T5	12
	Retainer, Reeves Inst. Corp.	A-SP-162	12
25	Helipot Shaft	6546AP253	1
21	5G Shaft	6546AP222	1
41	Flexible Coupling Assembly	6546AN051	1
	Arm and Ring Assembly	6546AN058	1
	Arm and Ring Assembly	6546AN059	1
	Coupling Shaft	6546AP570	1
	Clamp	6546AP592	1
	Angle	6546BP154	2
40	Marker Strip	6546CP088	1
38	Terminal Strip - 10 Terminal, H.B.Jones	142	2
	Reinforcing Plate	6546AP089	4

Reference Figure 3.27	Name of Part	Part Number	Number Required
	Terminal Bracket	6546BP191	2
	Rear Clip	6546BP113	2
	Angle	6546BP150	2
	Back Cover Plate	6546DP049	1
	Angle	6546BP187	1
39	Marker Strip	6546CP087	1
	Support Plate Clip	6546AP246	4
	Gear Guard	6546BP123	1
	Front Clip	6546AP130	4
	Side Cover Plate	6546DP048	2
	Front Cover Plate	6546CP089	1
	Angle	6546BP149	1
	Rear Clip	6546BP148	2
	Bottom Cover Plate	6546DP050	1
	Angle	6546BP152	1
	Top Cover Plate	6546DP047	1
	Angle	6546BP186	1
	Support Weldment	6546EP021	1
	Shim	6546AP272	4
	Angle	6546AP214	4

Note: Miscellaneous hardware not listed.

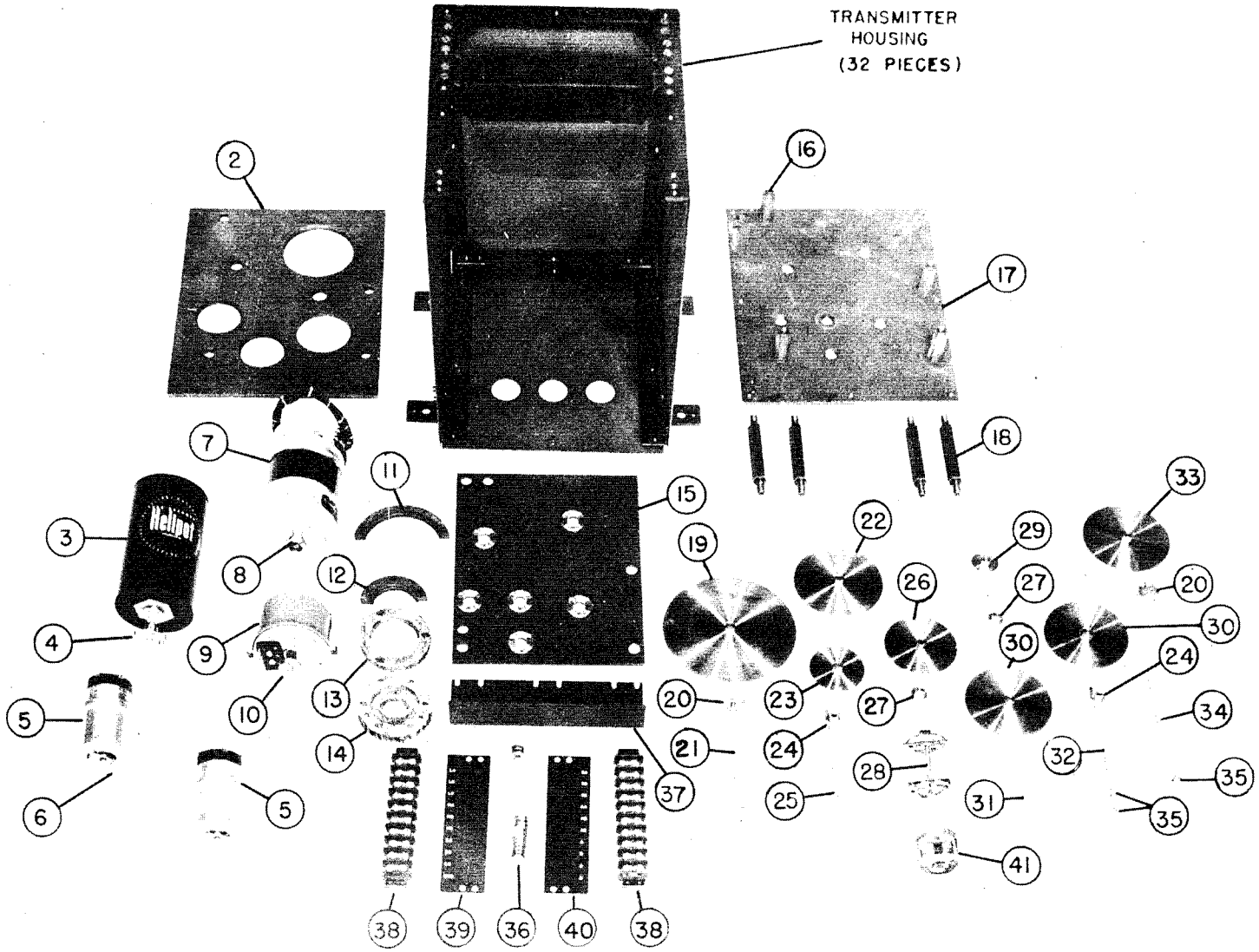


FIGURE 3.27 REGULATING-ROD POSITION TRANSMITTER - ROD NO. 15 DISASSEMBLED

14. Parts List - Regulating-Rod Position Indicating Unit 6546DN006

Reference Figure 3.28	Name of Part	Part Number	Number Required
	Cover Assembly	6546DN004	1
	Cover Weldment	6546EP006	1
	Window Frame	6546BP023	2
	Window Gasket	6546BP025	4
	Window	6546BP024	2
	Regulating Rod Position Mechanism Assy.	6546EN004	1
3,4,5,6	Synchro Coupling Assembly	6546BN001	2
8	Spring Coupling Assembly	6546AN002	2
15	48-Pitch Gear Assembly	6546BN002	2
17	183-Tooth Gear Assembly	6546AN008	1
35	80-Tooth Gear Assembly	6546AN006	1
18	48-Pitch Gear Assembly	6546BN003	1
34	40-Tooth Gear Assembly	6546AN007	1
38	Centimeter dial Assembly	6546AN004	1
28	48-Pitch Gear Assembly	6546BN004	2
37	Decimeter or Meter Dial Assembly	6546AN003	2
29	48-Pitch Gear Assembly	6546BN005	2
33	48-Pitch Gear Assembly	6546BN006	2
9	Gear Clamp - Reeves Instrument Corp.	A-SP-130	6
36	Ball Bearing - New Departure	R4-5C	12
10	Regulating Rod Indicator Housing	6546RP001	1
14	Collar	6546AP018	10
11	Coupling Shaft	6546AP022	1
16	48-Pitch Gear - Reeves Instrument Corp.	B-SP-648-24	2
12	Idler Shaft	6546AP023	1
13	Gear Shaft No. 1	6546AP024	1
23	Gear Shaft No. 2	6546AP025	3
26	Gear Shaft No. 3	6546AP026	1
32	Ball Bearing - New Departure	R4-T5C	8
30	48-Pitch Gear - Reeves Inst. Corp.	B-SP-648-27	2
7	Bearing Retainer No. 1	6546AP020	6
20	Bearing Retainer No. 2	6546AP021	2
31	48-Pitch Gear - Reeves Instr. Corp.	B-SP-648-36	3
24	Dial Shaft No. 1	6546AP027	1
22	Dial Shaft No. 2	6546AP028	2
44	Lamp Bracket	6546AP064	1
45	Candle Socket, Arrow	328	1
40	Face Plate	6546BP037	1
42	Vernier Shim	6546AP054	2
41	Vernier	6546AP043	1
27	Motor Gear	6546AP029	1
39	Plate Spacer No. 1	6546AP055	2
25	Motor - Diehl Mfg. Co.	FPE-25-11	1
43	Plate Spacer No. 2	6546AP056	2
2	Cover Plate	6546BP015	1
1	Cover Shim	6546AP030	2
19	Marker Strip	6546BP040	1

Reference Figure 3.28	Name of Part	Part Number	Number Required
21	Terminal Strip - H. B. Jones Co.	141-14	1
46	Lamp Shield	6546AP066	1
47	Lamp (125 V.) - General Electric Co.	656	1
	Regulating-Rod Position Mechanism Assy.	6546EN005	1
3,4,5,6	Synchro Coupling Assembly	6546BN001	2
8	Spring Coupling Assembly	6546AN002	2
15	48-Pitch Gear Assembly	6546BN002	2
17	183-Tooth Gear Assembly	6546AN008	1
35	80-Tooth Gear Assembly	6546AN006	1
18	48-Pitch Gear Assembly	6546BN003	1
34	40-Tooth Gear Assembly	6546AN007	1
38	Centimeter Dial Assembly	6546AN004	1
28	48-Pitch Gear Assembly	6546BN004	2
37	Decimeter or Meter Dial Assembly	6546AN003	2
29	48-Pitch Gear Assembly	6546BN005	2
33	48-Pitch Gear Assembly	6546BN006	2
9	Gear Clamp - Reeves Instrument Corp.	A-SP-130	6
36	Ball Bearing - New Departure	R4-5C	12
10	Regulating Rod Indicator Housing	6546RP001	1
14	Collar	6546AP018	10
11	Coupling Shaft	6546AP022	1
16	48-Pitch Gear - Reeves Instr. Corp.	B-SP-648-24	2
12	Idler Shaft	6546AP023	1
13	Gear Shaft No. 1	6546AP024	1
23	Gear Shaft No. 2	6546AP025	3
26	Gear Shaft No. 3	6546AP026	1
32	Ball Bearing - New Departure	R4-T5C	8
30	48-Pitch Gear - Reeves Inst. Corp.	B-SP-648-27	2
7	Bearing Retainer No. 1	6546AP020	6
20	Bearing Retainer No. 2	6546AP021	2
31	48-Pitch Gear - Reeves Instr. Corp.	B-SP-648-36	3
24	Dial Shaft No. 1	6546AP027	1
22	Dial Shaft No. 2	6546AP028	2
44	Lamp Bracket	6546AP064	1
45	Candle Socket, Arrow	328	1
40	Face Plate	6546BP038	1
42	Vernier Shim	6546AP054	2
41	Vernier	6546AP043	1
27	Motor Gear	6546AP029	1
39	Plate Spacer No. 1	6546AP055	2
25	Motor - Diehl Mfg. Co.	FPE-25-11	1
43	Plate Spacer No. 2	6546AP056	2
2	Cover Plate	6546BP015	1
1	Cover Shim	6546AP030	2
19	Marker Strip	6546BP041	1
21	Terminal Strip - H. B. Jones Co.	141-14	1
46	Lamp Shield	6546AP066	1
47	Lamp (125 V.) - General Electric Co.	656	1

Reference Figure 3.28	Name of Part	Part Number	Number Required
	Mounting Frame Assembly	6546DN003	
	Mounting Frame	6546DP008	1
	Spring Retainer	6546AP011	4
	Frame Support Bar	6546DP042	1
	Clamp	6546AP058	4
	Spacer	6546AP059	4
	Frame Support Bar	6546DP007	1

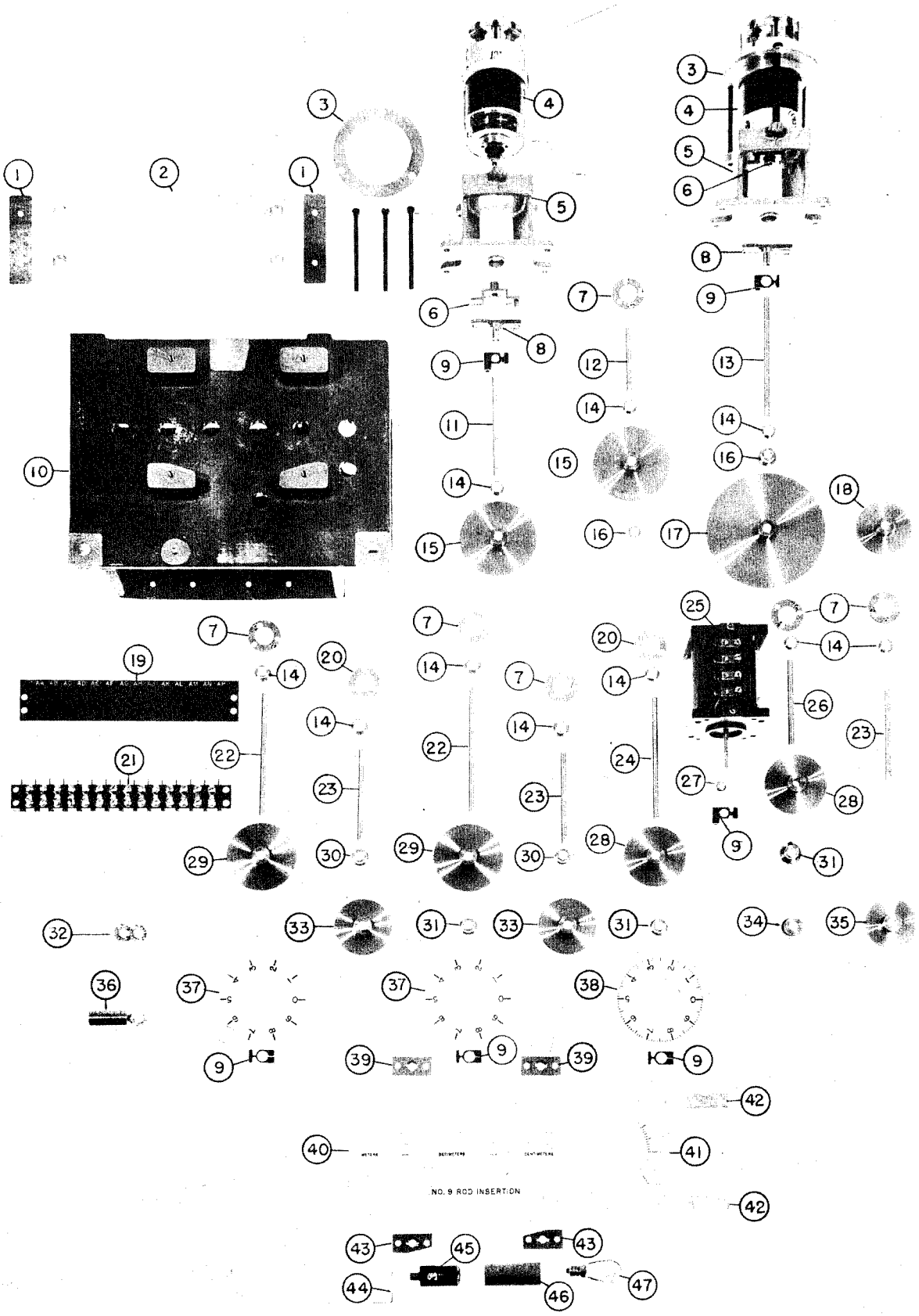


FIGURE 3.28 REGULATING-ROD POSITION INDICATING UNIT

15. Parts List - Emergency-Rod Position Transmitter Assembly 6546EN029

Reference Figure 3.29	Name of Part	Part Number	Number Required
	Synchro and Potentiometer Assembly	6546DN032	1
23	Coupling Assembly	6546AN050	1
5	5G Synchro Generator	Navy Type	1
7	5G Synchro Clamp	6546BP157	2
2	Support Plate	6546DP060	1
8	Synchro Ring	6546AP012	1
3	Potentiometer, Brown Instr. Co.	6546AP137	1
10	1G Synchro Generator	Navy Type	1
4	Male Coupling, Reeves Instr. Corp.	A-SP-111-1	1
6	5G Coupling, Reeves Instr. Corp.	A-SP-142	1
9	Mounting Plate	6546AP564	1
	Synchro Housing Altered	6546BP417	1
34	Flexible Coupling Assembly	6546AN051	1
	Arm and Ring Assembly	6546AN058	1
	Arm and Ring Assembly	6546AN059	1
	Coupling Shaft	6546AP570	1
	Clamp	6546AP592	1
	Gear Train Assembly	6546DN033	1
31	Gear and Hub Assembly	6546AN022	1
29	Gear and Hub Assembly	6546AN023	1
21	Gear and Hub Assembly	6546BN030	1
22	Gear and Hub Assembly	6546AN024	1
25	Gear and Hub Assembly	6546AN017	1
26	Gear and Hub Assembly	6546AN021	1
17	Gear and Hub Assembly	6546AN026	1
16	Spacer	6546BP170	4
13	Bearing Plate	6546CP062	1
15	Spacer	6546AP249	4
14	Front Plate	6546DP058	1
32	Shaft	6546AP222	1
30	Shaft	6546AP223	1
28	Gear, Reeves Instrument Corp.	B-SP-648-36	1
	Shaft	6546AP225	1
27	Shaft	6546AP221	1
24	Gear, Reeves Instrument Corp.	B-SP-648-48	1
	Retainer, Reeves Instrument Corp.	A-SP-162	10
18	Female Coupling, Reeves Inst. Corp.	A-SP-113-1	2
19	Shaft	6546AP224	1
20	Bearing, New Departure Div.	R-4T5	10
33	Collar, Reeves Instr. Corp.	A-SP-496	6
	Back Cover Plate	6546DP049	1
	Angle	6546BP154	2
	Rear Clip	6546BP113	2
	Support Plate Clip	6546AP246	4
	Angle	6546BP159	1
35	Gear Guard	6546BP155	1
	Front Clip	6546AP130	4
	Front Cover Plate	6546DP046	1

Reference Figure 3.29	Name of Part	Part Number	Number Required
	Side Cover Plate	6546DP048	2
	Top Cover Plate	6546DP047	1
	Rear Clip	6546BP148	2
	Bottom Cover Plate	6546DP050	1
12	Marker Strip	6546BP171	1
	Reinforcing Plate	6546AP089	2
	Terminal Strip Bracket	6546BP168	1
	Angle	6546BP152	1
	Angle	6546BP153	1
	Angle	6546AP214	4
	Support Weldment	6546EP021	1
	Shim	6546AP272	4
	Angle	6546BP149	1
	Angle	6546BP150	2
11	Terminal Strip-12 terminal, H. B. Jones	142	1

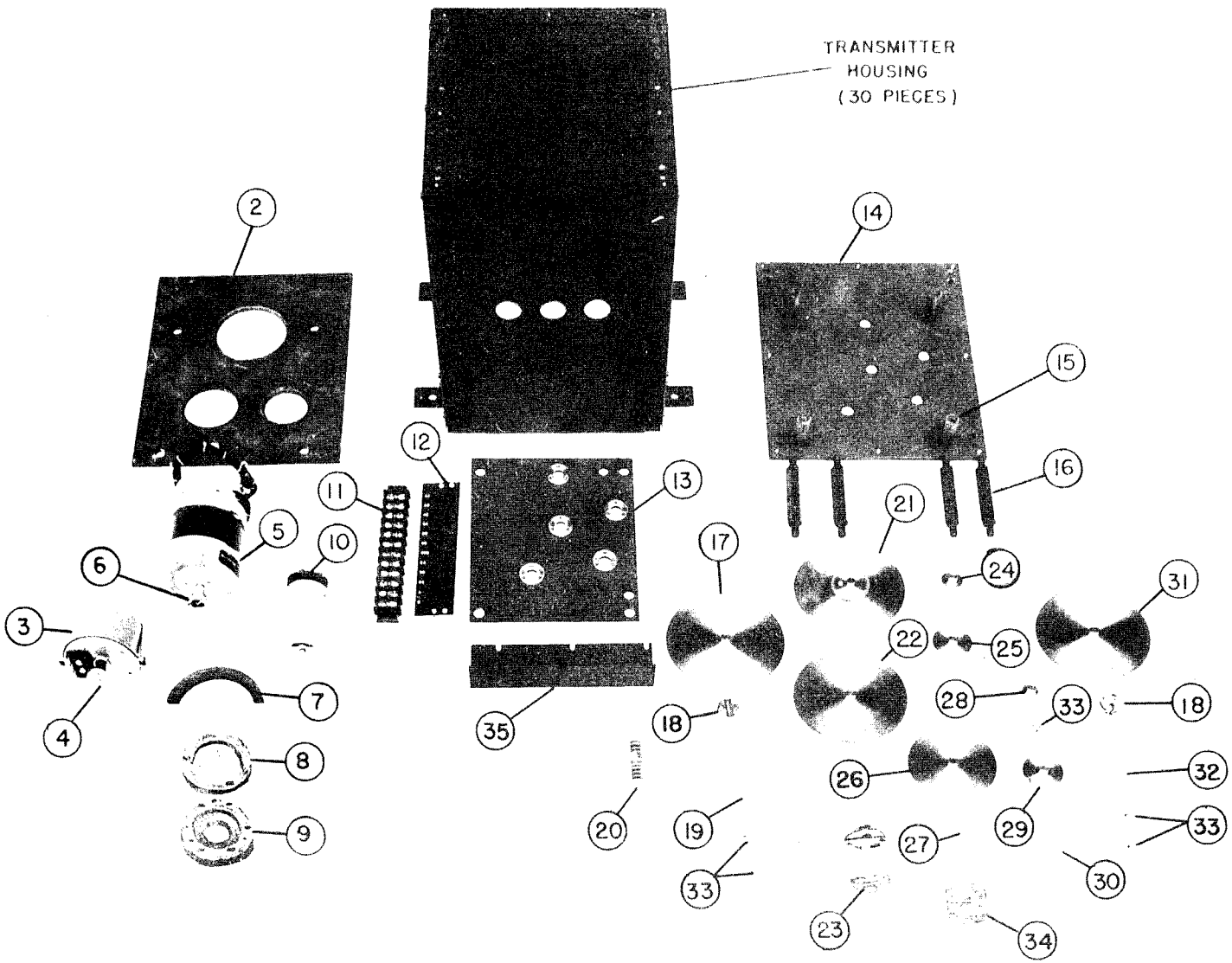


FIGURE 3.29 EMERGENCY-ROD POSITION TRANSMITTER DISASSEMBLED

16. Parts List - Emergency-Rod Position Indicating Unit 6546RN001

Reference Figure 3.30	Name of Part	Part Number	Number Required
	Emergency Rod Pos. Ind. Mech. Assy.	6546EN009	1
	Emergency Rod Pos. Ind. Mech. Assy.	6546EN010	1
	Emergency Rod Pos. Ind. Mech. Assy.	6546EN011	1
	Emergency Rod Pos. Ind. Mech. Assy.	6546EN012	1
	Emergency Rod Pos. Ind. Mech. Assy.	6546EN013	1
	Emergency Rod Pos. Ind. Mech. Assy.	6546EN014	1
	Emergency Rod Pos. Ind. Mech. Assy.	6546EN015	1
29	Dial Assembly (Coarse)	6546AN011	2
33	Index Plate and Pad Assy.	6546AN014	1
32	Dial Assembly (Fine)	6546AN012	2
30,31	Index Plate and Pad Assy.	6546AN013	1
19	48-Pitch Gear Assy.	6546BN012	4
24	48-Pitch Gear Assy.	6546BN013	2
2,3,4,5	Synchro Coupling Assy.	6546BN001	2
40	Nameplate Assembly	6546BN014	1
	Nameplate Assembly	6546BN015	1
	Nameplate Assembly	6546BN016	1
	Nameplate Assembly	6546BN017	1
	Nameplate Assembly	6546BN018	1
	Nameplate Assembly	6546BN019	1
	Nameplate Assembly	6546BN020	1
8	Spring Coupling Assembly	6546AN002	2
1	Emergency Rod Indicating Housing	6546RP003	1
11	Gear Clamp - Reeves Inst. Corp.	A-SP-130	4
14	Coarse Dial Shaft	6546AP074	2
12	Ball Bearing - New Departure	R4-5C	8
10	Bearing Retainer No. 1	6546AP077	6
15	Intermediate Shaft	6546AP071	2
20	Gear - Reeves Instr. Corp.	B-SP-648-30	4
16	Synchro Shaft	6546AP073	2
17	Fine Dial Shaft	6546AP075	2
25	Gear - Reeves Instr. Corp.	B-SP-648-27	2
23	Motor Gear	6546AP029	2
21	Gear - Reeves Instr. Corp.	B-SP-648-48	2
9	Bearing Retainer No. 2	6546AP079	2
18	Motor - Diehl	FPE-25-11	2
7	Bearing Retainer No. 3	6546AP080	2
6	Bearing Retainer No. 1	6546AP020	2
34	Marker Strip	6546CP019	1
	Marker Strip	6546CP020	1
	Marker Strip	6546CP021	1
	Marker Strip	6546CP022	1
	Marker Strip	6546CP023	1
	Marker Strip	6546CP024	1
	Marker Strip	6546CP025	1
28	Terminal Strip - H. B. Jones Co.	141-9	2

Reference Figure 3.30	Name of Part	Part Number	Number Required
27	Marker Strip	6546CP012	1
	Marker Strip	6546CP013	1
	Marker Strip	6546CP014	1
	Marker Strip	6546CP015	1
	Marker Strip	6546CP016	1
	Marker Strip	6546CP017	1
	Marker Strip	6546CP018	1
37	Lamp Shield	6546AP066	2
38	Candle Socket - Arrow	328	2
	Index Plate Shim	6546AP081	2
39	Plunger Switch - Micro-Switch Div.	BZ-2RQ1-SP-DT	2
35	Lamp Bracket	6546AP082	2
22	Gear Clamp	6546AP072	2
36	Lamp (125 V.) - General Electric Co.	625	2
13	Ball Bearing - New Departure Div.	R-4-T5C	8
26	Bearing Retainer No. 3	6546AP078	2
	Instrument Case and Mounting , M57	6546RP002	1
	Instrument Case	6546EP007	1
	Hinge Spacer	6546AP084	1
	Pin	6546AP085	1
	Panel Door	6546DP011	1
	Hinge	6546BP059	1
	Window	6546AP086	14
	Gasket	6546AP087	28
	Window Frame	6546BP060	1
	Window Frame	6546BP061	1
	Window Frame	6546BP062	1
	Window Frame	6546BP063	1
	Window Frame	6546BP064	1
	Window Frame	6546BP065	1
	Window Frame	6546BP066	1
	Window Frame	6546BP067	1
	Window Frame	6546BP068	1
	Window Frame	6546BP069	1
	Window Frame	6546BP070	1
	Window Frame	6546BP071	1
	Window Frame	6546BP072	1
	Window Frame	6546BP073	1
	Nut	6546AP093	2
	Lock Housing	6546AP092	2
	Lock - Brown Instrument Co.	73981	2
	Plate - Brown Instrument Co.	76027	2
	Key - Brown Instrument Co.	40039	2
	Set Screw - Brown Instrument Co.	41190	2

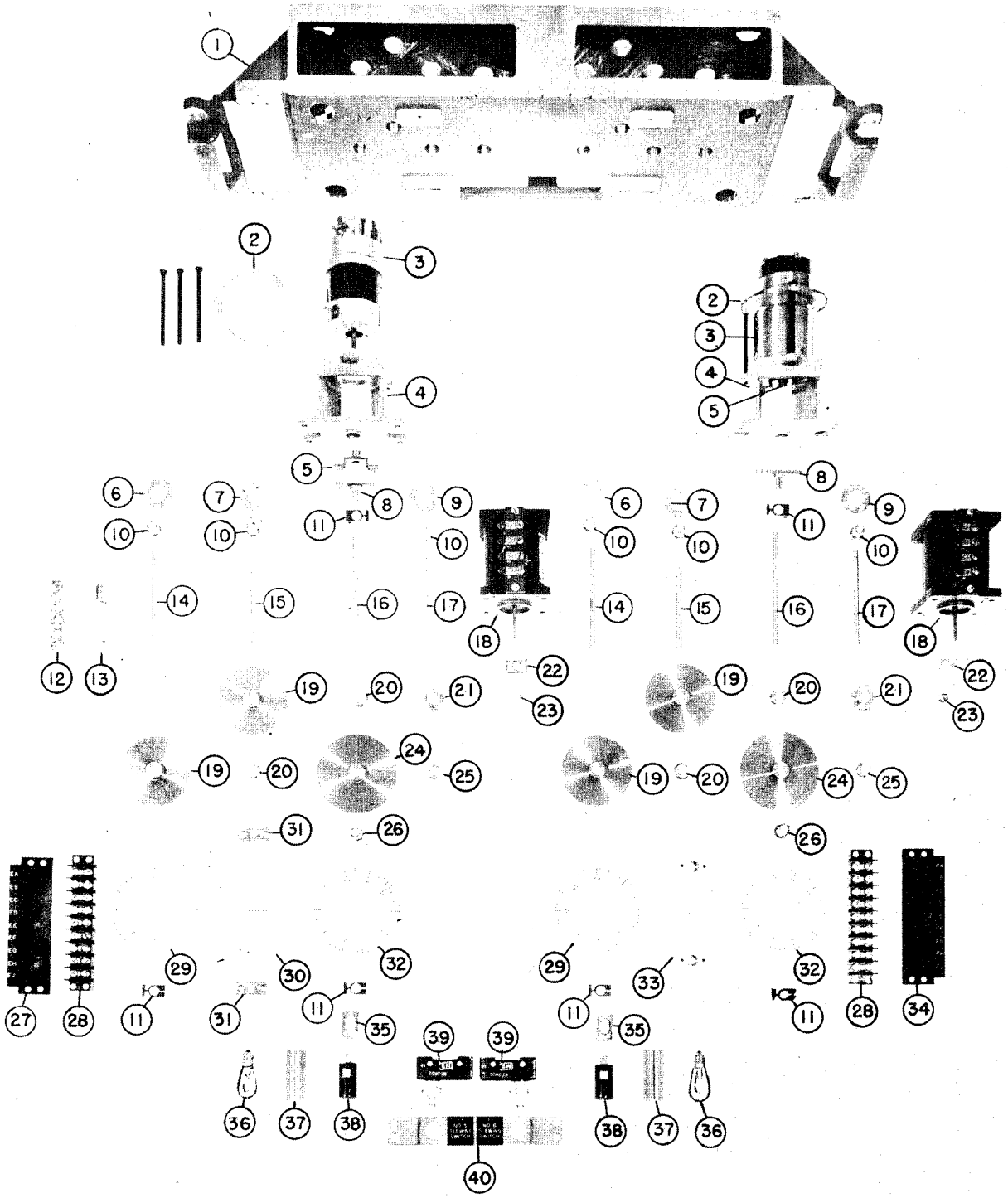


FIGURE 3.30 EMERGENCY-ROD POSITION INDICATING UNIT

17. Parts List - Coarse Rod-Position Indicator 6546EN018 and 6546EN019

Name of Part	Part Number	Number Required
Gear Train Assembly - L.H.	6546DN015	1
Shaft Assembly	6546AN020	2
Shaft Assembly	6546BN024	2
Shaft Assembly	6546BN023	2
Shaft Assembly	6546AN019	4
Shaft Assembly	6546AN018	2
Spacer	6546AP098	4
Connection Angle Weldment	6546CP030	1
Spacer	6546AP097	5
Connection Angle	6546BP081	1
L.H. Bearing Plate Weldment	6546DP019	1
Side Plate L.H.	6546DP018	1
Angle	6546BP093	1
Air Lock Fastener - United Carr Fastener Co.	99808	2
Bearing - Fafnir	F-4	24
Female Coupling - Reeves Instrument Corp.	A-SP-613	4
Baffle Drive Assembly	6546EN016	1
Baffle Assembly	6546AN015	8
Lead Screw Assembly	6546BN022	8
Angle	6546BN025	2
Bearing Retainer	6546AP109	8
Clamp	6546BP258	1
Support Strip	6546BP260	1
Ball-Bearing - New Departure Div.	R-4	8
Rod	6546BP098	8
Support Strip	6546BP261	1
Angle	6546CP028	1
Clamp	6546BP259	1
End Plate - R.H.	6546CP026	1
Angle	6546CP029	8
End Plate - L.H.	6546CP034	1
Gear Train Assembly - R.H.	6546DN016	1
Shaft Assembly	6546BN024	2
Shaft Assembly	6546AN020	2
Shaft Assembly	6546AN018	2
Shaft Assembly	6546AN019	4
Shaft Assembly	6546BN023	2
Connection Angle	6546BP080	1
Spacer	6546AP097	5
Connection Angle	6546BP076	1
Bearing Plate - R.H.	6546DP023	1
Spacer	6546AP098	4
Angle	6546BP088	1
Angle	6546CP033	1
Bearing Plate - R.H.	6546DP032	1
Bearing - Fafnir	F-4	24
Female Coupling - Reeves Inst. Corp.	A-SP-613	4

Name of Part	Part Number	Number Required
Blower Assembly	6546CN004	1
Blower Support Assembly	6546CN008	1
Blower - Eastern Air Devices, Inc.	J80A-C	1
Indicator Plate Assembly	6546DN011	1
Indicator Plate	6546DP005	1
Frame	6546DP014	1
Pad	6546BP085	2
Glass	6546AP450	1
Filter	6546AP453	1
Hinge	6546BP075	1
Pad	6546BP086	2
Round Head Wing Stud - Airlock	W99899-2-170	2
Stud Cross Pin - Airlock	99785-2	2
Glass	6546AP448	6
Filter	6546AP451	6
Glass	6546AP449	1
Filter	6546AP452	1
Spacer	6546AP367	7
Light Intensity Compensation Film	6546AP668	6
Light Intensity Compensation Film	6546AP669	2
Front Cover Assembly	6546EN020	1
	6546EN021	1
Front Cover Weldment	6546EP015	1
	6546EP016	1
Lamp - General Electric Co.	NE 51	16
Indicating Lamp - Dial Light Co.	8540SX-831	16
Terminal Board Assembly	6546CN007	1
	6546CN006	1
Plate Assembly	6546CN005	1
Terminal Strip - 17 Term - H. B. Jones	142	2
Terminal Strip Cover	6546BP094	2
Marker Strip	6546DP028	1
	6546DP031	1
Marker Strip	6546DP027	1
	6546DP030	1
Spacer	6546AP091	6
Reinforcing Plate	6546AP089	5
Terminal Board Assembly	6546DN012	1
	6546DN013	1
Plate Assembly	6546DN010	1
Terminal Strip Cover	6546AP101	1
Terminal Strip - 6 Terminal - H. B. Jones	142	1
Marker Strip	6546BP083	1
	6546BP084	1
Marker Strip	6546DP026	1
	6546DP029	1
Terminal Strip, 17 terminal - H. B. Jones	142	1
Terminal Strip Cover	6546BP094	1
Bracket	6546BP039	1

Name of Part	Part Number	Number Required
Bracket	6546AP090	1
Spacer	6546AP091	5
Reinforcing Plate	6546AP089	5
Condenser - Sprague Electric Company	PAB 14	1
Top Mounting Angle	6546CP011	1
Bottom Mounting Angle	6546CP031	1
Bottom Plate	6546DP015	1
Synchro Support Plate - L.H.	6546DP016	1
Angle	6546BP092	1
Angle	6546BP034	1
Synchro Support Plate - R.H.	6546DP017	1
Brace Angle	6546CP032	1
Support Angle	6546CP027	1
Top Cover	6546DP022	1
Insulation Strip	6546BP091	1
Lamp Socket	6546AP094	8
Lamp - G.E. Mazda	89	8
Floating Coupling - Reeves Inst. Corp.	A-SP-562-4	8
Male Coupling	6546AP115	8
Male Coupling - Reeves Instr. Corp.	A-SP-142	8
5F Synchro Motor	Navy Type	8
Synchro Clamp	6546BP043	16

18. Reference Drawings

Emergency-Rod Position Transmitter Layout	6546EL028
Regulating-Rod Position Transmitter Layout	6546EL031
Emergency-Rod Position Indicator Layout	6546EL036
Regulating-Rod Position Indicator Layout	6546RL002
Coarse Rod-Position Indicator Layout	6546RL007

19. Engineering Report References, D.I.C. 6546, M.I.T.

Design of Coarse-Rod-Position Indicator,
Engineering Report No. 22

Design of Regulating-Rod-Position Transmitter,
Engineering Report No. 23

Design of Emergency-Rod-Position Transmitter,
Engineering Report No. 24

Instrument Pinion Support,
Engineering Report No. 30

Rod-Position Recorders,
Engineering Report No. 36

Design of the Emergency-Rod-Position Indicator System,
Engineering Report No. 41

Design of the Regulating-Rod-Position Indicator System,
Engineering Report No. 42

Calibration Test of Emergency and Regulating-Rod Transmitter Amplifier and Indicators,
Engineering Report No. 44